MULTIPLE SINGLE-WAFER LOADLOCK WAFER PROCESSING APPARATUS AND LOADING AND UNLOADING METHOD THEREFOR

This invention relates to the loading and unloading of wafer processing machines and particularly to transferring substrates from batches of large semiconductor substrates between atmospheric pressure and high vacuum environments.

Background of the Invention:

The vacuum processing of semiconductor wafers requires the loading and unloading of wafers into and from wafer processing equipment in a manner that does not cause adverse atmospheric contamination of the high vacuum environment or wafers within the processing apparatus. In addition, in order to maximize wafer throughput, it is desirable to minimize the time it takes for a typical loading or unloading sequence to be carried out. Furthermore, as wafer sizes continue to increase, as with the current trend from 150 mm and 200 mm diameter wafers to 300 mm diameter wafers, it becomes increasingly more difficult to simultaneously satisfy both contamination and throughput requirements, resulting in a compromise solution that is often far from ideal. Still further, as the wafer value increases, such as in the later stages of processing and with increasingly larger wafers that contain more devices as well as more complex devices, the exposure to financial loss due to wafer damage from an apparatus failure increases, forcing higher reliability requirements on the wafer transfer apparatus.

The majority of the prior art semiconductor wafer vacuum processing systems currently in use utilize what is referred to as a Vacuum Cassette

Elevator (VCE) for wafer sizes up to 200 mm. An example of a VCE-equipped prior art wafer processing system 10 is diagrammatically illustrated in **Fig. 1**. The system 10 includes at least one VCE 11 which consists of a loadlock chamber 12 that can be pumped to high vacuum, an elevator assembly 13 located within the chamber 12, a front door 14 for operator access to load and unload a multiple-wafer cassette 15 when the chamber 12 is at atmospheric pressure, and a slit valve isolated interface port 16 that connects the VCE 11 to some form of wafer transfer module 17 for individually transferring wafers there through when the chamber 12 is at a high vacuum.

Typical operation of a processing apparatus 10 that is based on the use of a VCE 11 proceeds with an operator opening the door 14 of the VCE 11 and placing a new cassette 15 of wafers 18 on top of the elevator 13. The door 14 is then closed, followed by a pumping sequence which establishes an appropriate vacuum level in the VCE 11. The pumping time to arrive at a given vacuum pressure level is generally proportional to the volume of the VCE 11 and to the exposed inner surface area of the VCE 11 and of the wafers 18 contained therein. When the appropriate VCE vacuum level is reached, the isolating slit valve port 16 between the VCE 11 and transport chamber 17 is opened, permitting access to the VCE 11 by a robot arm 19 in the wafer transport module 17. The elevator 13 then positions the cassette 15 for access of the transfer arm 19 to a desired wafer 18 in the cassette 15. The robotic transfer arm 19 then extends into the VCE 11 through the slit valve port 16, captures the positioned wafer 18 and retracts back into the transport module 17 in preparation for delivery of the wafer 18 to an appropriate process module 20 of the apparatus 10. These steps are performed in reverse, with wafers being returned to a cassette 15 and the step of pumping the VCE 11 to vacuum being replaced by the step of venting the VCE 11 to atmosphere.

The prior art apparatus 10 of **Fig. 1** can be used for 300 mm wafers if open wafer cassettes of comparable size are also used. However, for a number of reasons, semiconductor device manufacturers who are the end users of the wafer processing equipment prefer, and are in the process of establishing a

standard for, a type of wafer carrier that is not high vacuum compatible and does not use a removable cassette 15. Such a carrier 25 is illustrated in **Fig. 2**. The carrier 25 includes a vertical array of horizontal wafer supporting rails 26 built into the carrier 25, typically at thirteen or twenty-~~six~~ Five equally spaced levels. The carrier 25 has a front door 27 which is normally closed during the transport of wafers 28 between different pieces of processing equipment.

Since the carrier 25 is not high vacuum compatible and contains no cassette or cassette elevator, wafers must be transferred at atmospheric pressure from the carrier 25 and into the wafer processing equipment. The straight forward method contemplated in the prior art is to transfer wafers 28 from the carrier 25 into processing apparatus such as machine 10 of **Fig. 1**. Where it is desired to place a full carrier 25 of, typically thirteen or twenty-six, wafers into a large VCE 11, one would have to devise a method for quickly moving wafers from the carrier 25 into the VCE 11. A single wafer serial transfer approach adds significant time to the loading and unloading cycles, and is therefore undesirable. A multiple wafer simultaneous transfer approach has been demonstrated in which wafers are transferred in one or two batches from the carrier 25 to the VCE 11. Such a parallel transfer approach, however, presents risk of multiple wafer damage due to a single equipment failure, which is a risk preferably avoided. Also, the likelihood of mechanically touching of the back side of a wafer that is positioned over another unprocessed wafer, which is difficult to avoid when wafers are transferred simultaneously, poses potential particulate contamination problems. In addition, with a VCE dimensioned to hold wafers that are 300 mm in diameter or larger, VCE pump-down and/or vent time can be unacceptably long, making the loadlock cycle a throughput limiting factor in the operation of the processing apparatus. To compensate for these delays with a compromise of pump-down or vent time can result in an increase in atmospheric contamination of the transfer chamber or in particulate contamination on the wafer or both.

With large diameter wafers, large high vacuum pumps are necessary to pump the large VCEs that the larger wafers require. Such large pumps are

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difficult to mechanically isolate from the VCEs, and as a result such pumps have a tendency to transmit vibrations to the VCE that can cause particles to fall from one wafer onto another wafer below. Similarly, it is believed that the up and down motion of elevators in VCEs can also contribute to an increased vibration-induced fall of particles from upper wafers to lower wafers. Vibration can also cause wafers to move out of their positions in the cassettes and to be out of the position necessary for pick up by the transfer arms.

Accordingly, there remains a need for loading and unloading wafers into and from wafer processing equipment from a non-VCE carrier in a manner that does not cause adverse atmospheric contamination of the high vacuum environment or the particulate contamination of wafers within the processing apparatus, and that does not limit wafer throughput of the equipment, particularly with large diameter wafers, such as those of 300 mm diameter or larger, and without increasing the risk of financial loss due to multiple wafer damage from an apparatus failure which would force higher reliability requirements to be placed on the wafer transfer apparatus.

Summary of the Invention:

It is a primary objective of the present invention to eliminate the need for large vacuum cassette elevator modules in semiconductor wafer processing machines and processes. It is further objective of the present invention to significantly reduce the time required for the pumping and venting of loadlocks in semiconductor wafer processing machines, and particularly to prevent loadlocks from being a throughput limiting factor.

It is a further objective of the present invention to reduce or avoid particulate contamination in the transfer of wafers into and out of processing machines. In particular, objectives of the present invention include the elimination of moving elevators as well as the vibration associated therewith that causes particle contamination problems, the reduction in size of high vacuum pumps and in the vibration due to pump operation, and the avoidance of the need to use large high vacuum pumps.

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It is a further objective of the present invention to provide improved wafer processing machine throughput, particularly for small batches of wafers, such as those used during wafer qualification. It is a particular objective of the present invention to reduce the possibility of the large VCEs and loadlocks becoming a throughput limiter for a wafer processing apparatus.

An additional objective of the present invention is to eliminate the need for simultaneous or parallel wafer handling, and particularly to thereby reduce the risk of damage to multiple wafers and the probability of particles failing on wafers.

A specific objective of the present invention is to provide that wafer throughput of a wafer processing machine is not impacted by wafer cooling and alignment.

According to the principles of the present invention, a wafer processing cluster tool is provided having a transfer or transport module with a high vacuum transfer mechanism therein which connects through a plurality of single wafer loadlocks with an atmospheric pressure front end module (AFE) that also has a transfer mechanism therein. The transfer mechanism in the transfer module moves wafers individually, between the loadlocks and processing modules, which connect through isolation valves with the transfer module, as well as among the processing modules, in a high vacuum environment. The transfer mechanism in the front end module moves individual wafers between the loadlocks and a plurality of multi-wafer carriers in an atmospheric pressure environment. Either the AFE transfer arm or each carrier is vertically moveable to allow selected individual wafers to be loaded to or unloaded from the carrier by horizontal translation of the wafer by the transfer arm. The connection between the AFE and the transfer module is made through a plurality of single-wafer loadlocks, preferably of the over-under type, which may have either the vacuum pressure side or the atmospheric pressure side on the top.

According to the preferred embodiment of the invention, the AFE includes a wafer aligner and provision for connection to two or three multiple-wafer carriers. At least one loadlock, and preferably each of the loadlocks, is capable

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of being operated as an inbound loadlock to transfer wafers into the vacuum. Similarly, at least one loadlock, and preferably each of the loadlocks, is capable of being operated as an outbound loadlock to transfer wafers out of the vacuum. Each of the loadlocks that is capable of operating as an outbound loadlock being also equipped with a cooling element to cool down the wafer, during the loadlock vent cycle, after the wafer has been processed and before the wafer is loaded back into a carrier. These outbound loadlocks with cooling elements are capable of supporting hot wafers, that are still at or near processing temperatures. Accordingly, such outbound loadlocks are preferably provided with high temperature compatible wafer supporting elements of, for example, metal. Preferably, a plurality of the loadlocks is used for both inbound and outbound wafers for optimum throughput with each equipped with cooling capability to permit continued operation if one loadlock were to fail.

In an alternative embodiment of the invention, separate dedicated inbound and outbound loadlocks are provided. In such a case, the dedicated inbound loadlocks need not be provided with cooling elements, which lowers their cost, and the supports for the substrates therein need not be capable of supporting wafers that are at high temperature. As a result, high friction elastomeric wafer support structure may be used to reduce the likelihood that a substrate supported thereon will be vibrated or jarred out of position, thereby permitting substrate movement at the loadlock to be carried out at higher speed. Similarly, because wafer alignment retention is not as critical with outbound wafers, a loadlock that is to be used for outbound transfer of wafers can also be operated at higher speed.

The AFE is also preferably maintained in a laminar flow environment. Preferably, the carriers are loaded to and from a loading position in the user's clean room environment from which they are transferred to adjacent an opening into the AFE portion of the apparatus and secured on structure that presents the carrier with its carrier door facing an opening to an inner AFE chamber, in a proper position and orientation for access to the wafers therein by the AFE transfer arm when the carrier access door is open. When so positioned and

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oriented, a mechanism in the AFE operates the door on the carrier to allow the access by the AFE transfer arm. When a carrier door is open, a laminar and preferably horizontal flow of clean air or other gas is maintained in the AFE to flow particles and gas away from the loadlocks and away from the carriers.

In accordance with the present invention, carriers are moved into position adjacent the opening to the AFE chamber while laminar flow of air is maintained in the AFE chamber. A carrier door is opened and a wafer, preferably the bottommost unprocessed wafer, is picked by the AFE transfer arm from the opened carrier and placed in an inbound single-wafer loadlock, which is open to the AFE chamber and sealed from the high vacuum chamber of the apparatus. The wafer in the inbound loadlock is set on the tops of raised lift pins and the transfer arm is withdrawn form the loadlock chamber. Then the inbound loadlock chamber is sealed from the AFE chamber, and the loadlock is pumped to a vacuum level that is compatible with the high vacuum level of the high vacuum transfer chamber. While the loadlock chamber is being pumped, the AFE transfer arm may remove another wafer from the same carrier or another carrier and hold the wafer in a position ready to be placed in an inbound loadlock chamber, or the AFE transfer arm may use the pump down time to remove a wafer from the outbound loadlock and place it in a carrier.

When the loadlock that is containing an inbound unprocessed wafer is pumped to the appropriate vacuum, the loadlock is opened to the high vacuum transfer chamber while the wafer on the lift pins is moved vertically into a position to be removed from the loadlock and transferred into one of the processing chambers. At this time a processed wafer is preferably removed from a processing chamber and placed in the same loadlock, and in most processes, throughput is optimized by doing so. Ideally, a wafer is always passing inbound through a loadlock when a loadlock is being pumped, and a wafer is always passing outbound through a loadlock when a loadlock is being vented. Alternatively, as stated above, one loadlock may be a dedicated inbound loadlock and another may be a dedicated outbound loadlock. In either event, when an outbound wafer is placed in a loadlock from the (HVBE) the high vacuum back end

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loadlock is then closed from the high vacuum transfer chamber and vented to atmosphere.

When a wafer has been processed, the wafer is transferred from the final processing chamber used in the process and into an outbound loadlock. The processed wafer is placed, by the transfer arm of the high vacuum transfer chamber, onto the raised lift pins on an elevator mounted support and the transfer arm is withdrawn from the loadlock, whereupon the wafer is moved vertically into the outbound loadlock chamber as the chamber is sealed from the high vacuum atmosphere. The pins in the support are then preferably lowered to set the wafer onto the support, whereupon, cooling tubes in the wafer support function to remove heat from the wafer and thereby cool the wafer to a temperature suitable for placing it in a carrier, since the carrier may not be compatible with temperatures that are as high as the temperature at which a wafer, which has just been processed, might be. The cooling rate and venting gas are selected to avoid contacting a hot wafer with air, which can degrade the wafer.

When a processed wafer has been cooled in a loadlock and the loadlock has been vented to the atmospheric pressure level of the AFE chamber, the loadlock is opened to the AFE chamber, the lift pins raise the wafer and the AFE transfer arm picks up the wafer and returns it to one of the carriers, preferably the one from which it was removed. The cycling of wafers from the carriers preferably includes the removal of the bottom wafer first, then each of the wafers sequentially from the bottom to the top of the carrier, as there is processing space for them in the high vacuum processing portion of the machine. The wafers, once processed, are returned to a carrier, typically in the same sequence in which they were removed, and placed in the same slot or position in the carrier from which they were removed. The carrier is thus refilled from the bottom to the top. A section of empty slots will thus be present in a carrier between the last wafer to be returned to the carrier, which is at the top of the partial stack of processed wafers extending from the bottom of the carrier, and

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the next unprocessed wafer to be removed for processing, which is at the bottom of the partial stack of unprocessed wafers that extends to the top of the carrier.

According to certain aspects of the present invention, carriers of processed wafers in the AFE can be exchanged with carriers of unprocessed wafers while wafers of another carrier are being cycled by the AFE transfer arm to and from the loadlocks. In this case, structure may be optionally provided to restrict the flow of air between the portion of the AFE chamber being occupied by the carrier that is in use and the portion occupied by the carrier or carriers being changed.

In the preferred embodiment of the invention, wafers being loaded from a carrier to an inbound loadlock pass through a wafer aligning station, which angularly orients a flat or other reference on the wafer relative to the transfer arm of the AFE. The aligner may also center the wafer on the transfer arm but, preferably, measures the off-center *x-y* distances so that transfer arm movement can be controlled to compensate for the off-center distances. Throughput is enhanced by locating the aligner in the AFE rather than in the high vacuum. During all handling of wafers referred to above, the wafers are preferably maintained in a horizontal orientation, with the device side thereof facing upward. Preferably also, most of the motion of wafers in the AFE, among the loadlocks, the aligner and the carriers, is preferably carried out with edgewise motion of the wafers in a common plane, with only the wafer motion necessitated to select a wafer from and return a wafer to the proper position involving motion with a vertical component. Similarly, the motion of wafers among the loadlocks and the processing stations in the transfer chamber is carried out with edgewise motion of the wafers in a common plane. The planes of motion in the AFE and transfer chambers are preferably vertically spaced, with the motion between the vertically spaced planes taking place by transfer of the wafer through a loadlock, which is preferably exclusively by vertical motion. The transfer arms also undergo a slight vertical motion when placing a wafer on or lifting a wafer from the pins of the loadlock elevator.

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The present invention eliminates large VCEs and the long pump and vent times that are associated with them, particularly where they are designed for and contain large wafers. Accordingly, better throughput is achieved, particularly with small batches of wafers, and loadlock operation is not likely to be a throughput limiter. Particularly, time is made available for replacing a carrier with another carrier of wafers without adversely affecting machine throughput. No carrier movement occurs once the wafers are inserted in position to be loaded into the machine. The picking of one wafer from above another wafer, and the potential for the dropping of particles on the lower wafer that this creates, is avoided. The high vacuum pumps for loadlock pumping are reduced in size with the present invention, which reduces the cost, the cycle time, and potential vibration that can increase particulate contamination and unwanted vibration induced wafer movement within the carriers. Single wafer movement in and out of the carrier is provided using industry proven robot transfer devices. With the present invention, a standard atmospheric aligner can be used providing lower cost, less complicated handling and faster operation than with high vacuum aligners. Two or three carriers can be accommodated in the preferred embodiments of the invention. The single wafer over-under loadlocks are easily equipped with the contamination avoidance features of U.S. Patents Nos. 5,237,756 and 5,205,051 expressly incorporated herein by reference herein.

These and other objectives of the present invention will be readily apparent from the following detailed description of the present invention in which:

Brief Description of the Drawings:

Fig. 1 is an elevational cross-sectional diagram of a VCE equipped cluster tool of the prior art.

Fig. 2 is a perspective view of an industry proposed wafer carrier that is not high vacuum compatible and does not use a removable cassette.

Fig. 3 is a top view diagram of a multiple single-wafer loadlock equipped wafer processing apparatus according to one preferred embodiment of the present invention.

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Fig. 4 is a cross sectional view along line **4-4** of **Fig. 3** illustrating a single-wafer loadlock in the open position.

Figs. 4A , 4B and **4C** are sequential views of the loadlock of **Fig. 4** illustrating the passage of a wafer there through from the atmospheric environment to the high vacuum environment.

Detailed Description of the Preferred Embodiments:

Referring to **Fig. 3**, one preferred embodiment of a semiconductor wafer processing apparatus 30 is diagrammatically illustrated. The apparatus 30 includes two basic parts, a high vacuum back end (HVBE) 31 and an atmospheric front end (AFE) 32. The HVBE 31 includes a transfer chamber 33 to which are connected a number of process chambers 34, illustrated as four modules 34a-34d, but which can include five or more such modules. The transfer chamber 33 has a pivotal and extendable wafer transfer arm 35 of a commercially available type, mounted therein on a vertical axis 36, which is capable of moving wafers individually among the processing modules 34 and to and from a plurality of load lock stations, which are preferably two or three in number, and illustrated as including a first loadlock station 37a at which wafers are loaded into the HVBE 31 from the AFE 32, and a second loadlock station 37b at which wafers are unloaded from the HVBE 31 and back to the AFE 32. The HVBE 31, including the transfer chamber 33 and the processing chambers 34, contains a high vacuum during the operation of the processing apparatus 30, while the AFE 32 contains air or other gas, such as a dry inert gas, at an ambient or atmospheric pressure level. The processing chambers 34 each communicate with the transfer chamber 33 through a slit valve 38 that is in the horizontal plane of the transfer arm 35 and through which the arm 35 moves wafers individually into and out of the processing chamber 34 from and to the transfer chamber 33.

The AFE 32 includes a plurality of carrier support stations 40, each of which is capable of supporting a carrier 25 of the style having no separately removable cassettes such as that illustrated in **Fig. 2**. The number of carrier stations is preferably two or three, with two such stations 40a and 40b being

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illustrated. The carrier stations 40 each accept either a batch of wafers in a vertical rack or carrier, preferably in the form of either the 300 mm carriers 25 or the conventional open wafer cassettes of the type that were typically used in VCEs (**Fig. 1**). The AFE 32 also includes a wafer aligner station 41 and a wafer transfer device robot, preferably in the form of an extendable wafer transfer arm 42 of a commercially available type, that pivots on a vertical axis 43. The arm 42 transfers individual wafers to and from the carriers 25 at the carrier stations 40a,40b, to and from the aligner station 41, and to and from the loadlock stations 37a and 37b. The aligner station 41 is equipped with a wafer aligner of any of several commercially available types, such as for example an optical aligner, that orients the wafer on the arm 42 and measures any off-center distance so that the machine controller can compensate for any such off-center distance with compensating transfer arm movements. . The AFE 32 is provided with a sheet metal enclosure 39 that surrounds the transfer arm 42, the aligner station 41 and the atmospheric side of the loadlock stations 37a and 37b. In the enclosure 39 are a plurality of openings 44, one at each of the carrier stations 40a,40b. The openings 44 are shaped to allow the placement of the fronts of the carriers 25 in such a position that they substantially cover the openings with the doors 27 thereof facing or projecting through the openings so that wafers from inside a carrier 25 are accessible by the transfer arm 42 when a carrier door 27 is open.

In the illustrated embodiment of the apparatus 30, at least one carrier loading station 70 is provided in the user's clean room environment. The station 70 includes a platform or carriage (not shown) positioned to receive and present a carrier 25 respectively from and to an operator or robotic carrier handling device for loading and unloading wafers to and from the apparatus 30. The platform or carriage of the loading station 70 should have carrier handling capabilities that will permit automatic movement of a carrier 25 between the loading station 70 and either one of the carrier stations 40a,40b.

At each of the loadlock stations 37, an independently operable, single-wafer loadlock 45 is provided, which is part of and built into an upper or lower

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horizontal wall of the HVBE 31. The loadlocks 45 permit the passage of individual wafers from the atmospheric environment of the AFE 32 to the high vacuum environment of the HVBE 31 while maintaining isolation between the two atmospheres. Each of the loadlocks 45 is provided with a high vacuum cryogenic pump 46 that is operable to pump the loadlock 45 to a fairly high vacuum pressure level but not necessarily to the level of the HVBE 31. The pumping takes place with the loadlock 45 sealed (**Fig. 4**) around a wafer being moved into the HVBE 31 from the AFE 32. The loadlocks 45 are also each provided with vent valve structure 39, which is operable to vent the loadlock 45 at a controlled rate to atmospheric pressure with introduction of a gas that may be of the type present in the AFE 32, when the loadlock 45 is sealed around a wafer being moved into the AFE 32 from the HVBE 31.

The loadlocks 45 enclose a sealable loadlock chamber 47 that has a volume limited to that necessary to contain a single large wafer on a wafer transfer support 48, as illustrated in more detail in **Fig. 4**. Each loadlock 45 is located at an opening 50 in a wall 51, for example the horizontal top wall, between the transfer chamber 33 and the AFE 32. Each loadlock 45 is provided with a vertically moveable downwardly-facing upper cup-shaped chamber cover 52 that moves downwardly against the upper wall 51 of the transfer chamber 33. The cover 52 is provided with an annular seal 55 around the perimeter of the bottom rim thereof to seal the loadlock chamber 45 from the atmospheric pressure environment within the AFE 32 by the selective downward activation of the cover 52. The cover 52 is raised upwardly to allow transfer of a wafer into or out of the loadlock 45 by the AFE transfer arm 42.

Similarly, on the bottom side of the wall 51 beneath the opening 50 is provided a vertically moveable wafer elevator 56 that includes the wafer support 48 in an upwardly facing orientation, and an upwardly-facing cup-shaped housing 57. The housing 57 is provided with an annular seal 58 around the perimeter of the upper rim thereof to seal the loadlock chamber 47 from the low pressure environment within the HVBE 31 by the selective upward activation of the housing 57. The housing 57 is raised upwardly to allow transfer of a wafer

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into or out of the loadlock 45 by the HVBE transfer arm 35. The wafer support 48 preferably includes an array of lift pins 59 that can be lowered and raised in synchronism to move a wafer to or from the surface of the support 48. Normally, the pins 59 are in a raised position to facilitate a handoff of a wafer between the transfer arms 35 and 42 and the support 48. For such a handoff, the transfer arms 35 and 42 shift a gripped wafer vertically between a plane defined by the tops of the raised pins and a slightly higher horizontal plane in which the wafer is horizontally moved into and out of the loadlock chamber 47. In the two way loadlocks illustrated, the pins 59 are made of a high temperature tolerant material such as a metal. Where a loadlock is a dedicated inbound loadlock, the pins need not have the capability of lowering a wafer to a cooling platform and may therefore be fixed pins on the support 48..The pins in a dedicated inbound loadlock need not be of a heat tolerant material and are therefore preferably made of a high friction material that will permit faster operation of the platform without movement of the wafer thereon.

In the operation of the loadlock 45 in a loading process (that is, a process which moves a wafer into the HVBE 31 for further transfer and processing in the vacuum environment), before transfer of a wafer from the AFE 32 into the loadlock station 37 for transfer into the HVBE 31, the loadlock 45 will have been vented to the atmosphere of the AFE 32 and the cover 52 will have been raised, opening the loadlock 45 to the inside of the AFE chamber 32, as illustrated in **Fig. 4**. In this state, the housing 57 will have been raised to seal the loadlock 45 from the high vacuum atmosphere of the HVBE 31. With the pins 59 raised, the AFE transfer arm 42 extends to center a wafer 60 in the loadlock chamber 47 in the horizontal plane of the transfer arm 42, above the planes of the tips of the raised pins 59 and of the upper wall 51 of the transfer chamber 33. As illustrated in **Fig. 4A**, when wafer 60 is centered in the loadlock chamber 47, the arm 42 lowers slightly toward the support 48 to set a wafer 60 on the pins 59. As illustrated in **Fig. 4B**, the arm 42 is then retracted and the cover 52 is lowered in place, and the small volume of the chamber 47 is evacuated by operation of the pump 46. When the evacuation cycle is complete, the bottom elevator

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unit 56 is lowered into the high vacuum of the transfer chamber 33 where the wafer 60 is removed by the movement of the HVBE transfer arm 35 into engagement with the wafer 60 and the lifting of the wafer 60 off of the pins 59, as illustrated in **Fig. 4C**.

A reversal of the loading process described above allows a completed wafer 60 to be returned to its original spot in the AFE 32. The operation of the loadlock 45 in an unloading process (that is, a process which moves a wafer from the HVBE 31 after processing in the vacuum environment of a process chamber 34 and into the AFE 32 for return to a carrier 25), begins with the loadlock 45 evacuated to the vacuum pressure of the transfer chamber 33, the cover 52 lowered to seal the loadlock chamber 47 from the atmospheric environment of the AFE 32, and the housing 57 lowered to open the loadlock 45 to the inside of transfer chamber 33 of the HVBE 31. With the pins 59 raised, the HVBE transfer arm 35 extends to center wafer 60 in the loadlock chamber 47 in the horizontal plane of the transfer arm 35, as illustrated in **Fig. 4C**. Then, the arm 35 lowers slightly to set the wafer 60 on the tips of the pins 59, whereupon the wafer 60 is released by the arm 35 and the arm 35 is withdrawn from the loadlock chamber 47. The elevator 56 is then raised until the housing 57 seals the loadlock chamber 47 from the vacuum atmosphere of the transfer chamber 33, as illustrated in **Fig. 4B**. Then, the small volume of the chamber 47 is vented by controlled operation of the valve 39 to the atmospheric environment of the AFE 32. When the venting cycle is complete, the cover 52 is raised and the wafer 60 is removed by the movement of the AFE transfer arm 42 under the wafer 60, as illustrated in **Fig. 4A**, and the lifting of the wafer 60 from the pins 59 by the transfer arm 42 as illustrated in **Fig. 4**.

It is desirable to provide cooling of a wafer 60 after processing in the HVBE 31, and prior to exposure of the wafer 60 to normal atmosphere. This need may be provided only by one loadlock station, such as station 37b. Preferably, however, at least two or all of the loadlocks 47 are equipped with cooling capability so that any loadlock station 37 may be used for outboard wafers to optimize throughput. The loadlocks 45 are provided with such wafer

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cooling capability that is accomplished during the time it takes to vent the output loadlock at station 37b so there is no throughput loss due to the cooling. To achieve this, the upper surface of the support 48 in the elevator 56 in the loadlock 45 is a water cooled, wafer support plate . This plate is designed with three or more small elevated areas 66 which actually support the wafer 60 when the pins 59 that have been holding the wafer 60 have been lowered into the support 48. The height of the elevated areas is chosen to avoid heat transfer by direct conduction and to thereby slow the cooling rate down and thereby prevent undesirable wafer warpage that might otherwise occur, since no physical clamping of the wafer is provided. Pressure control to regulate the cooling rate is avoided as that would defeat the objective of being able to vent the load lock in a time frame that maximizes wafer throughput.

The use of single-wafer loadlocks 45 in combination with batch carriers 25 permits the overall volume and total exposed surface area to be reduced to a small fraction of what is found in a loadlock sized for and containing a full cassette of wafers, as in **Fig. 1**. The use of single-wafer loadlocks in place of full cassette loadlocks significantly reduces the time required to move small batches of wafers, for example qualification wafers, into and out of the apparatus 30. Further, during venting and pumping sequences, a single-wafer loadlock 45 allows use of the contamination prevention features described in U.S. patents nos. 5,205,051 and 5,237,756, hereby expressly incorporated herein by reference herein, to reduce contamination due to either particulate or moisture condensation.

The loading of the machine 30 may be carried out by an operator, but is preferably carried out by a robot, which places a carrier 25 that is loaded with a plurality of unprocessed wafers, for example, a full standard batch of thirteen or twenty-~~six~~ Five 300 mm wafers, in position at the loading station 70 of the AFE 32, as illustrated in **Figs. 3** and **4**. Then a transfer mechanism (not shown but represented by arrows 71), move the carrier 25 from the loading station 70 to one of the carrier stations 40, for example station 40a, with the door 27 of the carrier 25 locked and facing the axis of the AFE transfer arm 42 through one of

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the openings 44. So positioned, the carrier 25 is engaged by a locking and unlocking mechanism 72 within the AFE that mechanically interacts with the carrier 25 to automatically unlock the door 27. Then, the mechanism 72 moves the carrier door 27 away from the carrier 25 and then down, thereby opening the carrier 25 and exposing a selected wafer to transfer arm 42. In this condition, the carrier 25 occupies one of the openings 44 in wall 74 in the AFE 32 to loosely isolate the inside of the AFE 32 from the clean room environment, thereby allowing for relaxation of the clean room standards and providing further particulate isolation within the AFE 32. Preferably, the arm 42 first positions vertically adjacent the lowermost position of the carrier 25 so that the bottom wafer in the carrier 25 is first picked up by the wafer transfer arm 42 for transfer. In this way, particles in the carrier 25 that are dislodged by the removal of a wafer from the carrier 25 will not fall on the upwardly facing surface of an unprocessed wafer where they could cause defects in processing.

When the arm 42 is properly positioned adjacent the carrier 25 for the removal of the first wafer, preferably from the bottom of the stack of wafers in the carrier 25, the transfer arm 42 picks the wafer from the carrier 25, moves it through the aligning station 41 where any off center distance of the wafer is measured and the wafer is properly oriented on the transfer arm 42. The arm 42 then deposits the wafer in a loadlock, for example, the loadlock 37a, compensating for any measured off-center distance. Once in the loadlock, the wafer is moved from the AFE 32 into the HVBE 31 in the manner described above. The arm 42 indexes vertically to bring it in to alignment with the next lowermost wafer to be picked up on the next return of the transfer arm 42 to the carrier station 40a.

After a wafer has been removed from the loadlock 45 at the loadlock station 37a and cycled through the processing stations 34 by the transfer arm 35 of the transfer chamber 33, the arm 35 places the wafer preferably in a loadlock 45 that is already open to the ~~camber~~ CHAMBER 33, through which it passes as described above. After passing through the loadlock 45, the wafer is preferably moved by the AFE transfer arm 42, preferably back to the same

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position in the same carrier 25 from which the wafer was removed, for example, back into the carrier 25 at the carrier station 40a. In moving from a loadlock station 37 to a carrier 25, the aligner station is usually bypassed. However, having the aligner in the front end allows for wafer realignment prior to insertion into the carrier, should that be desired, without impacting back end processing in the HVBE 31. This outbound wafer alignment capability may be desirable if a wafer becomes misaligned during the cooling and loadlock vent cycle to the point where it might drag along the inside walls of the wafer carrier 25, which could increase particle problems. When all of the wafers in the carrier 25 at the carrier station 40 have been processed, the door 27 on the carrier 25 is closed and the locking and unlocking mechanism 72 is disengaged. Then, the carrier 25 is moved to the loading station 70 from which it may be removed by an operator or robot.

During the loading and unloading of wafers to and from a carrier 25 at a carrier station 40, a carrier 25 can be removed from the other station 40 and replaced with another carrier 25 of wafers to be cycled through the HVBE 31. During this and all operations within the AFE chamber, cross particulate contamination risk is reduced by a laminar flow of filtered air that preferably moves horizontally in a transverse elevation in the AFE 32. Any structure, represented diagrammatically as a blower 75 and a filter 76, that is effective to produce the laminar flow referred to herein that will produce the results satisfactory to one skilled in the art is acceptable.

The front end configuration outlined above easily allows for the addition of a third wafer carrier station 40, if necessary, for example at the position occupied by the wafer aligner, which can be relocated.

Advantages of the preferred configuration of the loadlocks 45 are most effectively realized by configuring the loadlock 45 to have as small a volume as practical, preferably not more than about six liters and preferably only about 4.5 liters. The volume of the loadlock chamber 47, is exaggerated in **Figs. 4-4C**, as the lower surface of the chamber cover 52 may be shaped to lie within 20 to 30 thousands of an inch from a wafer supported on the pins 59, when elevated.

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Similarly, the height of the pins 59 in their elevated positions is also exaggerated in the figures, and need be only enough to allow for transfer to and from the transfer arms and clearance with the raised surfaces 66 during transfer. Preferably, the chamber 47 is flat and round, or at least nearly round, to minimize wasted volume, thereby making higher speed pumping and venting more easily achievable. In addition, the vertical transfer direction of the loadlocks 45 in the preferred over and under configuration yields a more robust low volume lock structure. With such a configuration, the lock can be machined in a structural wall of the HVBE 31 so that the mounting and connecting of vacuum pumps to the loadlocks 45 results in minimal vibration. Avoiding the location of time or space consuming processes in the loadlocks 45, such as preheating and degassing processes, avoids making the loadlocks throughput limiting. The over-under version provides the low vibration while maintaining a small footprint.

The single loading station 70 that is illustrated in **Fig. 3** facilitates the design and use of a track based carrier delivery system by the user with which carriers 25 are delivered and taken from the loading station 70. In addition, one or more buffer positions 78 may be established along the paths illustrated by the arrows 71 in which to temporarily park one or more carriers 25, such as incoming carriers of unprocessed wafers. This facilitates the exchange of carriers 25 between the machine 10 and a single carrier handler at the station 70. For example, with a carrier 25 at each of the stations 40a and 40b, a carrier 25 of unprocessed wafers can be delivered to loading station 70 then moved toward station 40a, where it can be parked at a position along the arcuate one of the arrows 71, to the right of station 70 in the figure. Then the carrier 25 can be transferred from the station 40b to the station 70 where it is removed by the robot, whereupon the incoming carrier parked to the left of the station 70 can be transferred to the location 40b. Other combinations of movements can be provided with additional buffer stations 78.

Those skilled in the art will appreciate that the applications of the present invention herein are varied, and that the invention is described in preferred

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embodiments Accordingly, additions and modifications can be made without departing from the principles of the invention. What is claimed is:

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CLAIMS:

1. A method of transferring wafers between multi-wafer carriers and a high vacuum environment of a transfer chamber of a wafer processing cluster tool, the method comprising the steps of:

positioning a first multi-wafer carrier in communication with a clean atmospheric environment adjacent to a robot transfer device that is located in an atmospheric front end of the tool; then

transferring a first individual wafer with the robot transfer device from the first carrier and into a first single-wafer loadlock, operating as an inbound loadlock, that is open to the atmospheric environment and sealed from the high vacuum environment of the transfer chamber; then

sealing the first loadlock from the atmospheric environment; then

pumping the first loadlock to a vacuum pressure level; then

opening the first loadlock to the high vacuum environment; then

removing the first wafer from the first loadlock with a transfer arm located in the transfer chamber and placing the first wafer into a vacuum processing chamber when in communication with the high vacuum environment; then

removing the first wafer with a transfer arm from a vacuum processing chamber when in communication with the high vacuum environment and placing the first wafer into the first or a second single-wafer loadlock, operating as an outbound loadlock, that is open to the high vacuum environment and sealed from the atmospheric environment; then

sealing the outbound loadlock from the high vacuum environment; then

venting the outbound loadlock to a pressure level of the atmospheric environment; then

opening the outbound loadlock to the atmospheric environment; then

transferring the first wafer from the outbound loadlock to the carrier.



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2. The method of claim 1 further comprising the steps of:

simultaneously with the first loadlock pumping step, transferring a second individual wafer with the robot transfer device between a carrier and the second loadlock with the second loadlock open to the atmospheric environment and sealed from the high vacuum environment of the transfer chamber.

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3. The method of claim 1 further comprising the steps of:

simultaneously with the first loadlock pumping step:

transferring a second individual wafer with the robot transfer device between the first carrier and the second loadlock with the second loadlock open to the atmospheric environment and sealed from the high vacuum environment of the transfer chamber; and

with a transfer arm located in the transfer chamber, transferring a third wafer through the transfer chamber from one vacuum processing chamber to another vacuum processing chamber.

4. The method of claim 1 wherein the outbound loadlock venting step includes the step of actively cooling the wafer in the outbound loadlock.

5. The method of claim 1 further comprising the steps:

when the first and second loadlocks are sealed to both the atmospheric environment and the high vacuum environment; moving a wafer with the robot transfer device in the atmospheric environment and moving a wafer with the transfer arm in the high vacuum environment.

6. The method of claim 1 further comprising the steps of removing the first carrier from adjacent the robot transfer device in the atmospheric environment and replacing it with a second multi-wafer carrier by positioning the second carrier in combination with the atmospheric environment adjacent the robot transfer device while wafers from a third carrier are being transferred to and from the loadlocks by the robot transfer device.

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7. The method of claim 1 wherein:

the step of transferring the first individual wafer from the first carrier and into the first single-wafer loadlock includes the step of transferring the wafer to and from an alignment station in the atmospheric environment.

8. The method of claim 1 wherein:

the steps of the process are performed with the wafers in a horizontal orientation;

the transfers of wafers into and the removal of wafers from the loadlocks are carried out with substantially horizontal movements of the wafers; and

the method further includes the steps of moving the wafers vertically when within each of the loadlocks.

9. The method of claim 1 wherein:

the steps of the process are performed with the wafers in a horizontal orientation;

the transfers of wafers into and the removal of wafers in the high vacuum environment from the loadlocks and into and from the processing chambers are carried out with substantially horizontal movements of the wafers in a first horizontal plane;

the transfers of wafers into and the removal of wafers in the atmospheric environment to and from the loadlocks are carried out with substantially horizontal movements of the wafers in a second horizontal plane spaced vertically from the first horizontal plane; and

the method further includes the steps of moving the wafers vertically when within each of the loadlocks between the first and second horizontal planes.



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10. A method of manufacturing a semiconductor wafer comprising the steps of::

positioning a first carrier in communication with a clean atmospheric environment adjacent a robot transfer device that is located in an atmospheric front end of the tool; then

transferring a first individual wafer with the robot transfer device from the first carrier and into a first single-wafer loadlock that is open to the atmospheric environment and sealed from the high vacuum environment of the transfer chamber; then

sealing the first loadlock from the atmospheric environment; then

pumping the first loadlock to a vacuum pressure level; then

opening the first loadlock to the high vacuum environment; then

removing the first wafer from the first loadlock with a transfer arm located in the transfer chamber and placing the first wafer into a vacuum processing chamber when in communication with the high vacuum environment; then

processing the wafer in the processing chamber; then

removing the first wafer with a transfer arm from a vacuum processing chamber when in communication with the high vacuum environment and placing the first wafer into the first or a second single-wafer loadlock, operating as an outbound loadlock, that is open to the high vacuum environment and sealed from the atmospheric environment; then

sealing the outbound loadlock from the high pressure environment; then

venting the outbound loadlock to a pressure level of the atmospheric environment; then

opening the outbound loadlock to the atmospheric environment; then

transferring the first wafer from the second loadlock to the carrier.



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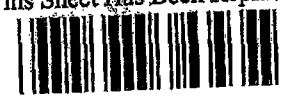
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11. The method of claim 10 wherein:

the steps of transferring the wafer with the transfer arm in the transfer chamber, placing the wafer into the vacuum processing chamber, processing the wafer in the processing chamber and removing the wafer from the vacuum processing chamber include the steps of sequentially transferring the wafer with the transfer arm to and from a plurality of vacuum processing chambers and processing the wafer in each of the processing chambers.



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12. A high vacuum wafer processing apparatus comprising:

a plurality of vacuum processing chambers having a port therein for loading and unloading wafers individually there through;

a high vacuum transfer chamber having a plurality of ports communicatable with the ports of the processing chambers;

an atmospheric front end chamber having at least one carrier loading and unloading door;

a plurality of single wafer loadlock chambers, each having an access opening therein between the high vacuum transfer chamber and the front end chamber, each loadlock having a vacuum side closure selectively openable between the opening and the high vacuum transfer chamber and an atmospheric side closure selectively openable between the opening and the front end chamber;

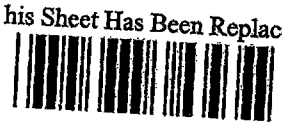
a plurality of carrier stations in the front end chamber configured to support a multiple-wafer carrier thereat;

a transfer arm in the high vacuum transfer chamber having a single-wafer engaging element thereon moveable to and from each of the processing chambers and loadlocks; and

a wafer transfer device in the front end chamber moveable among the loadlocks and the carriers.



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13. The apparatus of claim 12 further comprising:

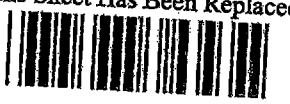
a wafer aligner in the front end chamber;

the wafer transfer device being also moveable to and from the wafer aligner.

14. The apparatus of claim 12 wherein:

gas affecting structure in the front end chamber.

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15. The apparatus of claim 12 further comprising:

a wafer cooler in at least one of the loadlocks situated to cause a flow of heat from the wafer to the cooler during venting of the loadlock.

16. The apparatus of claim 15 wherein:

the at least one loadlock includes an upwardly facing wafer support surface having the wafer cooler therein; and

the wafer support including a set of at least three lift pins having a raised position whereat a wafer is situated for handoff between the support and the transfer arm or the transfer device and a lowered position whereat the wafer is in contact with the support surface.

17. The apparatus of claim 12 wherein:

the loadlocks each include a wafer elevator moveable between a vacuum transfer position and an atmospheric transfer position; and

the transfer arm, the ports of the processing chambers and the vacuum transfer positions of the loadlocks are located in a common horizontal plane.

18. The apparatus of claim 12 wherein:

the loadlocks each include a wafer elevator moveable vertically between a vacuum transfer position and an atmospheric transfer position; and

the transfer device is horizontally moveable in a horizontal plane that contains the atmospheric transfer positions of the loadlocks.



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19. The apparatus of claim 18 wherein:

the carrier has a plurality of wafer storage positions vertically spaced in a vertical stack therein;

the carrier stations each include a carrier elevator operable to move a selected one of the plurality of wafer storage positions into the horizontal plane; and

the transfer device is horizontally moveable in the horizontal plane between the atmospheric transfer positions of the loadlocks and the selected one of the storage positions.

20. The apparatus of claim 18 wherein:

the carrier has a plurality of wafer storage positions vertically spaced in a vertical stack therein;

the transfer device being vertically moveable between the horizontal plane to the level of a selected one of the storage positions.

21. The apparatus of claim 12 wherein:

the single wafer loadlock chambers, when closed to the atmospheric and high vacuum chambers, enclosing an evacuable volume therein substantially less than the volume required to contain a multiple wafer carrier.

22. The apparatus of claim 12 wherein:

the single wafer loadlock chambers are of configured to support a wafer in a plane with the closures thereof configured for the transfer of wafers into and out of the chamber thereof in a direction perpendicular to the plane, whereby, when the plane is horizontal, the loadlock chambers are of an over-under type.

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23. The apparatus of claim **12** wherein:

the apparatus includes a high vacuum back end portion that includes the plurality of vacuum processing chambers and the high vacuum transfer chamber bounded by walls separating the a vacuum environment within the back end from an external environment; and

the single wafer loadlock chambers are mounted in a wall of the back end with one closure thereof in on the vacuum environment side of the wall and one closure on the side of the wall opposite the vacuum environment.



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