

APPARATUS WITH A VALVE AND METHOD OF OPERATION

FIELD OF THE INVENTION

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The present invention generally relates to substrate processing methods and apparatus, in particular to chemical deposition methods and deposition reactors. More particularly, but not exclusively, the invention relates to atomic layer deposition (ALD) reactors with pulsing valve(s) attached to a reaction chamber.

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BACKGROUND OF THE INVENTION

This section illustrates useful background information without admission of any technique described herein representative of the state of the art.

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ALD is based on strictly separated pulses of gases. Precursor gases that are released into a reaction chamber should react with each other on a substrate surface. Any reaction in gas phase is not preferred. The number of pulsing valves required to feed in reactive chemical(s) depends on used technology. In the case of photon-enhanced or plasma-assisted processes only a single pulsing valve may be needed while in conventional processes a plurality of pulsing valves are used. In order to achieve the highest quality required for modern semiconductor products there should not be mixing of precursor gases, in the gas phase, not even in ppm scale. Any such mixing is likely to cause particle formation, and is thus likely to cause damage on patterns on the substrate.

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The conventional approach to prevent the mixing of the gases is to purge the reaction chamber and related gas lines a sufficiently long time. However, as the ALD pulses may need repeating thousands of times, and the purge time is directly increasing the process time, having long purge times is not an optimum solution. Also, certain precursor chemicals start to decompose quickly in the used temperatures, and they cannot wait for the next chemical pulse for a long time.

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US 9,029,244 B2 demonstrates a 4-way valve solution for continuous purge gas flow where purge gas flows continuously along a purge gas line into a reaction chamber via the 4-way valve. However, due to the used valve design, the 4-way valve, when in closed state, contains a vertical cavity extending from the by-passing purge gas line to a valve diaphragm. The space formed by the cavity is sufficient to contain in it or absorb on its walls an undesired amount of precursor chemicals. Fluid passing by along the purge gas line will create turbulence in the described cavity, and there is a risk that precursor chemical trapped within the cavity is sucked by the by-passing purge gas flow towards the substrate and cause undesirable particle formation on substrate surface.

SUMMARY

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It is an object of embodiments of the invention to provide an improved apparatus and method with no trapped precursor chemical thereby avoiding undesired particle generation, while enabling high pulsing speed, or at least to provide an alternative to existing technology.

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According to a first example aspect of the invention there is provided an apparatus, comprising:

a reaction chamber to accommodate a substrate to be processed;

a pulsing valve fluidly connected to the reaction chamber (530, 1430), the pulsing valve comprising:

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a reactive chemical inlet to receive reactive chemical;

a reaction chamber outlet to mediate provided fluid connection of the pulsing valve to the reaction chamber;

a closure to control fluid flow from the reactive chemical inlet in the pulsing valve to the reaction chamber outlet; and

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an additional flow channel inlet or outlet to continuously purge the closure through the additional flow channel during an entire substrate processing cycle or sequence.

In certain example embodiments of the present disclosure the reactive chemical inlet is denoted as “a reactive chemical receiving inlet”, and the reaction chamber outlet as “an outlet towards the reaction chamber”.

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In certain example embodiments, the apparatus comprises the closure having an open and closed configuration to open and close, respectively, or at least partially close a route from the reactive chemical inlet to the reaction chamber outlet.

10 In certain example embodiments, the apparatus comprises the closure having only a steady configuration, the apparatus being configured to adjust fluid flow with the aid of flow controlling elements positioned in flow channels in fluid communication with the pulsing valve. Accordingly, in these embodiments the “closure” may be a stationary flow guiding element.

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In certain example embodiments, the closure has an open and closed configuration to open and close, respectively, the route from the reactive chemical inlet to the reaction chamber outlet.

20 In certain example embodiments, the apparatus is a substrate processing apparatus, such as a vacuum deposition reactor, for example, an atomic layer deposition reactor. The reaction chamber may accommodate a substrate or a plurality of substrates, i.e., at least one substrate to be processed.

25 In certain example embodiments, the apparatus is configured to purge, during the entire substrate processing cycle or sequence, the entire surface area of the closure exposed to processing gases. In particular, this may be interpreted to contain all open (i.e., non-covered) areas of the closure that are exposed to a precursor gas flow at least during certain periods of the deposition cycle or
30 sequence. These open areas include exposed areas that are not contacted by any fixed part of the valve.

In certain example embodiments, the apparatus is configured to purge the parts of

the pulsing valve from which reactive chemical can flow towards the reaction chamber.

5 In certain example embodiments, the apparatus is configured to purge the closure during an entire substrate processing cycle. In certain example embodiments, the apparatus is configured to purge the closure during an entire substrate processing sequence.

10 In certain example embodiments, the gas arrived at the reactive chemical inlet may be reactive gas or reactive gas mixed with (inactive) carrier gas or inactive gas only. Nitrogen as an example can be used as the carrier and/or inactive gas.

15 In certain example embodiments, the additional flow channel inlet or outlet is a waste channel outlet. In certain example embodiments, the waste channel is routed from the pulsing valve, bypassing the reaction chamber, to a particle trap and/or vacuum pump.

20 In certain example embodiments, the apparatus further comprises a vacuum chamber surrounding the reaction chamber. In certain example embodiments, the reaction chamber is configured to operate in vacuum conditions. Accordingly, in certain example embodiments said vacuum chamber surrounding the reaction chamber provides "another vacuum chamber".

25 In certain example embodiments, the apparatus comprises the pulsing the pulsing valve within the vacuum chamber on the outside of the reaction chamber in a heated area defined by the vacuum chamber. Accordingly, in certain example embodiments, the pulsing valve is a hot valve. Herein, the term hot valve means a valve that is being heated, for example, by a surrounding gas or with the aid of a heater. Heating may thus be implemented by means of a heating arrangement
30 included in the pulsing valve configured to operate the pulsing valve at an elevated temperature (equals to the "hot valve"), wherein the term "elevated temperature" is defined, within the present disclosure, as a temperature above the ambient temperature (i.e., higher than about 20 degrees Celsius). In some instances, the

pulsing valve can be operated at 22 degrees Celsius; in some other instances – at 25 degrees Celsius.

5 In certain example embodiments, the additional flow channel is a smaller channel, in terms of a cross-sectional flow area, compared to a flow channel providing the reactive chemical inlet.

In certain example embodiments, the flow direction of the purge is along the surface of the closure.

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In certain example embodiments, the apparatus is configured to purge the closure during the entire substrate processing cycle or sequence. In certain example embodiments, said “configured to” means that the apparatus is programmed to operate as desired. In certain example embodiments, the apparatus comprises a control system enabling said programming by computer program code means. In 15 certain example embodiments, the apparatus is programmed to purge the closure, during the entire substrate processing cycle or sequence, by reactive chemical or by fluid flowing from the reactive chemical inlet.

20 In certain example embodiments, the apparatus comprises a suction channel on the reactive chemical inlet side of the closure to enable a reactive chemical flow through the reactive chemical inlet to the suction channel to purge the closure. In certain example embodiments, the apparatus comprises a suction channel on the reactive chemical inlet side of the closure to enable a reactive chemical flow from 25 the reactive chemical inlet to purge the closure on its way from the reactive chemical inlet to the suction channel.

In certain example embodiments, the apparatus is configured (or programmed) to provide the suction channel with suction during the entire substrate processing cycle or sequence. 30

In certain example embodiments, the pulsing valve further comprising a carrier gas inlet fluidly connected to the reaction chamber via the reaction chamber outlet. In

certain example embodiments, the pulsing valve comprises the carrier gas inlet in fluid communication with the reaction chamber outlet. In certain example embodiments, the flow path from the carrier gas inlet to the reaction chamber is an unrestricted flow path.

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In certain example embodiments, the apparatus is configured to pulse reactive chemical into a carrier gas flow that is configured to flow from the carrier gas inlet to the reaction chamber outlet. In certain example embodiments, the apparatus is configured to pulse reactive chemical into a carrier gas flow flowing from the carrier gas inlet towards the reaction chamber via the reaction chamber outlet.

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In certain example embodiments, a reactive chemical flow arriving at the reactive chemical inlet already is a mixture of reactive chemical and carrier gas.

15 In certain example embodiments, there are means adopted to modify pressure or flow rate of the reactive chemical or carrier gas used to purge the closure. In certain example embodiments, these include an outgoing flow control. In certain other embodiments, these include an incoming flow control. In yet other embodiments, these include an incoming and outgoing flow control.

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In certain example embodiments, the pulsing valve is embedded into or forms part of a reaction chamber wall or lid.

25 In certain example embodiments, the additional flow channel resides within a flow channel providing the reactive chemical inlet.

In certain example embodiments, the additional flow channel has a cross-sectional flow area that is less than 25 % of the cross-sectional flow area of a flow channel providing the reactive chemical inlet.

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In certain example embodiments, the waste channel has a cross-sectional flow area that is less than 25 % of the cross-sectional flow area of a flow channel providing the reactive chemical inlet.

In certain example embodiments, a flow channel providing the reactive chemical inlet resides within the additional flow channel.

- 5 In certain example embodiments, the flow path from the carrier gas inlet to the reaction chamber is unrestricted.

In certain example embodiments, the pulsing valve is implemented without non-continuously purged gaps.

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In certain example embodiments, the pulsing valve further comprising a heating arrangement configured to operate the pulsing valve at an elevated temperature.

- 15 In certain example embodiments, the closure is of convex form. In certain example embodiments, the closure is of convex form in both in its closed and open configuration. In certain example embodiments, the general convex form does not change in a transition from the closed to the open configuration. For example, the transition is performed without a deformation of the general form, or the transition is performed without buckling of the closure.

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In certain example embodiments, the transition from the open configuration to the closed configuration is actuated by an actuating element. In certain example embodiments, the said actuation is performed by mechanical actuation. In other embodiments, other types of conventional actuation methods are used.

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- 30 In certain example embodiments, the transition from the open configuration to the closed configuration is actuated by pushing the closure against a sealing surface or ring defining or surrounding an opening. In certain example embodiments, the valve comprises an opening that the closure is configured to open and close to open and close, respectively, the route from the reactive chemical inlet to the reaction chamber outlet. In certain example embodiments, the said opening is the opening defined or surrounded by the sealing surface or ring.

In certain example embodiments, the transition from the open configuration to the closed configuration is implemented by moving the closure into a more convex form than in said open configuration. In certain example embodiment, the closure then contacts the edge(s) of the opening. In certain example embodiments, said opening is an opening between a first flow channel and a second flow channel, wherein the first flow channel via the pulsing valve provides the reactive chemical inlet and waste line outlet and the second flow channel via the pulsing valve the inactive or carrier gas inlet and reaction chamber outlet. In certain example embodiments, the gas flow within the second flow channel is unrestricted. For example, there are no flow obstacles within the channel on the way from the pulsing valve to the reaction chamber wall or lid (nor in the pulsing valve).

In certain example embodiments, the flow channel guiding gas to purge a center area of the closure (in its closed configuration) is implemented without sharp changes in flow direction (within the area of the pulsing valve). In certain example embodiments, the changes in flow direction in that channel are gentle. In certain example embodiments, the flow path in that flow channel is a curved path without any angles. In certain example embodiments all changes in flow directions within the pulsing valve are gentle, i.e., non-sharp. In certain example embodiments, all changes in flow directions are less than 90 degrees, in certain example embodiments less than 60 degrees, in certain example embodiments less than 45 degrees.

In certain example embodiments, the closure is attached to or sealed against a valve body at an attachment point or area. In certain example embodiment, the attachment is a fixed attachment. In certain example embodiments the closure extends, in its moving direction (the direction in which the closure or actuator moves in the transition from the open configuration to the closed configuration), in the closed configuration into a level that is farther away than the level of the attachment point or area at which the valve is attached to the valve body.

In certain example embodiments, said continuous purge of the closure does not occur through the additional flow channel or does not occur through the additional

flow channel during the entire substrate processing cycle or sequence. For example, when the closure is in the open configuration, the purge in certain example embodiments is implemented from the inlet(s) to the reaction chamber outlet. In certain example embodiments, the additional flow channel is closed or at least partially closed when the closure is in the open configuration.

According to a second example aspect of the invention there is provided a method, comprising:

supplying reactive chemical through a pulsing valve along a route extending from a reactive chemical inlet to a reaction chamber outlet of the pulsing valve; controlling the closing of the route by a pulsing valve closure; and purging the closure continuously through an additional flow channel during an entire substrate processing cycle or sequence.

In certain example embodiments, the reactive chemical is guided further to the reaction chamber via the reaction chamber outlet of the pulsing valve.

In certain example embodiments, the continuous purge of the closure is implemented via an additional flow channel inlet or outlet. Accordingly, the direction of flow may be to (the direction of) the additional flow channel or from (the direction of) the additional flow channel.

In certain example embodiments, the method comprises:

purging the closure at the area of the reactive chemical inlet continuously by said reactive chemical during the entire substrate processing cycle or sequence; and purging the closure around that area continuously by carrier gas.

In certain example embodiments, the method comprises:

providing the pulsing valve with a heating arrangement to operate the pulsing valve at an elevated temperature.

Further example aspects and their embodiments are presented as follows:

According to a third example aspect of the invention there is provided a computer

program product (or computer program) comprising program code executable by at least one processor in a control system of a substrate processing apparatus, the program code, when executed by the at least one processor, causing the substrate processing apparatus to perform the method of the second aspect and/or any of its embodiments.

According to a fourth example aspect of the invention there is provided a pulsing valve, comprising:

- a reactive chemical inlet to receive reactive chemical;
- 10 a reaction chamber outlet to fluidly connect the pulsing valve to a reaction chamber;
- a closure to control fluid flow from the reactive chemical inlet in the pulsing valve to the reaction chamber outlet; and
- an additional flow channel inlet or outlet to continuously purge the closure through
- 15 the additional flow channel during an entire substrate processing cycle or sequence.

In certain example embodiment, the closure has an open and closed configuration to open and close, respectively, a route from the reactive chemical inlet to the reaction chamber outlet.

According to a fifth example aspect there is provided an apparatus, comprising:

- a reaction chamber to accommodate a substrate to be processed;
- a flow guiding device fluidly connected to the reaction chamber, the flow guiding
- 25 device comprising:
 - a reactive chemical inlet;
 - a reaction chamber outlet; and
 - a flow guiding element for routing incoming gas from the reactive chemical inlet to the reaction chamber outlet or to another outlet.

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In certain example embodiments, the flow guiding device comprises an inactive or carrier gas inlet. In certain example embodiments, said another outlet is a waste line outlet. In certain example embodiments, the apparatus comprises a control

system providing pressure-based control of flow rate from the reactive chemical inlet to the reaction chamber outlet and to said another outlet. In certain example embodiments, the control system comprises a pressure changing device to cause a change in pressure (within a pipeline). In certain example embodiments, the device causing a change in pressure is positioned in a pipeline providing said another outlet. In certain example embodiments, the apparatus is programmed to maintain a flow from the reactive chemical inlet to the reaction chamber outlet and to said another outlet and from the inactive or carrier gas inlet to the reaction chamber outlet during an entire substrate processing cycle or sequence.

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In certain example embodiments, there is provided a pulsing valve with a cylinder route for precursor to bypass a valve membrane, and a waste line starting from a face of the membrane on the side of a precursor line.

15 In certain example embodiments, there is provided a deviation in which a line loops over a valve membrane having therein a flow restrictor.

According to a sixth example aspect there is provided an apparatus, comprising:
a reaction chamber;

20 a pulsing valve attached to the reaction chamber, the pulsing valve comprising:
a reactive chemical inlet;
a reaction chamber outlet; and

a closure having an open and closed configuration to open and close, respectively,
a route from the reactive chemical inlet to the reaction chamber outlet, the
25 apparatus further comprising:
an additional cleaning chemical inlet at the reaction chamber side of the closure to
purge the closure.

In certain example embodiments, the closure provides a valve output surface
30 pointing to or towards the reaction chamber, and the apparatus comprises the
additional cleaning chemical inlet to purge the valve output surface.

In certain example embodiments, the valve output surface is the surface of the

closure pointing to an output direction of the reaction chamber outlet. Accordingly, in certain example embodiments, the valve output surface is defined as a part of the closure pointing towards the reaction chamber (reaction chamber interior, or substrate). In certain example embodiments, the closure is a closing member, such as a membrane, a diaphragm, or an orifice plunger. In certain example embodiments, the closure or closing member is of solid material. In other embodiments, the closure is of non-solid material, such as fluid, or a combination of solid and non-solid material. Accordingly, the closure may be alternatively implemented by, for example, a drop of liquid metal capable of closing the route from the reactive chemical inlet to the reaction chamber outlet. In certain example embodiments, the membrane (or other closure) is facing the substrate, or reaction chamber interior. The expression membrane is to be considered interchangeable with closure, and with its different forms, such as plunger or fluid closure.

15 In certain example embodiments, the closure and/or valve output surface is in a fluid-flowing-pass contact with a cleaning chemical, or inert gas.

In certain example embodiments, the additional cleaning chemical inlet points directly or at least obliquely to the closure and/or valve output surface.

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In certain example embodiments, the additional cleaning chemical inlet points towards the closure and/or valve output surface from the reaction chamber side of the closure.

25 In certain example embodiments, the reaction chamber outlet provides a reaction chamber outlet channel towards the reaction chamber. In certain example embodiments, the reaction chamber outlet, or reaction chamber outlet channel, provides an opening towards the reaction chamber. The reaction chamber outlet of the pulsing valve in an example embodiment opens directly, without an intermediate part, to an interior of the reaction chamber.

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In certain example embodiments, the additional cleaning chemical input is additional to the parts the pulsing valve would typically have. Accordingly, in

certain example embodiments, the additional cleaning chemical input is additional to the reaction chamber outlet and/or reaction chamber outlet channel.

5 In certain example embodiments, the apparatus comprises the additional cleaning chemical inlet in a reaction chamber outlet channel wall.

10 In certain example embodiments, the apparatus comprises a pipe (cleaning chemical inlet pipe) extending towards the closure and/or valve outlet surface within the reaction chamber outlet channel, the pipe providing the additional cleaning chemical inlet.

In certain example embodiments, inert purge gas is directed to the proximity of the membrane with a pipe from the same space as the reaction space.

15 In certain example embodiments, the apparatus is configured to provide continuous purge of the closure and/or valve output surface.

20 In certain example embodiments, the apparatus is configured to provide purge along the closure and/or valve output surface.

In certain example embodiments, the flow direction of the cleaning chemical is first perpendicular to or oblique with respect to the closure and/or valve output surface, and upon hitting the closure and/or valve output surface the flow direction turns in parallel to the closure and/or valve output surface. When the cleaning chemical subsequently exits into the direction of the reaction chamber, also the remainder of the reaction chamber outlet channel becomes purged.

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30 In certain example embodiments, the apparatus comprises a pulsing valve or other means, such as mass flow controller, to change the cleaning chemical flow rate as needed. In certain example embodiments, the cleaning chemical flow is synchronized with reactive chemical pulses.

In certain example embodiments, the apparatus provides for a first flow path via

the pulsing valve to the reaction chamber, and has a second flow path intersecting the first flow path at the valve output surface to purge the valve output surface.

5 In certain example embodiments, the apparatus comprises a heated outer chamber around the reaction chamber.

In certain example embodiments, the apparatus comprises the pulsing valve in a heated intermediate space within the outer chamber but on the outside of the reaction chamber.

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In certain example embodiments, the pulsing valve comprises a chemical waste line outlet.

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In certain example embodiments, the apparatus provides a route by-passing the closure from the reactive chemical inlet to the waste line outlet that route being open in the closed configuration of the closure.

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In certain example embodiments, the apparatus is configured to maintain a higher pressure in a chemical waste line beginning at the waste line outlet compared to a pressure in the reaction chamber.

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In certain example embodiments, the closure is configured to prevent reactive chemical from flowing into the chemical waste line outlet when being in the open configuration.

In certain example embodiments, the chemical waste line comprises a flow restrictor that may be a narrow passage or a capillary.

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In certain example embodiments, the apparatus comprises an outlet other than the reaction chamber outlet. The other outlet may be the afore-mentioned waste line outlet. In certain example embodiments, the other outlet is connected to a same foreline, or exhaust line, to which the reaction chamber is connected. In certain example embodiments, the other outlet is connected to the same foreline, via a

trap (for chemical neutralization or combustion) positioned before the connection to the foreline. In certain example embodiments, the other outlet is connected to a different foreline. In certain example embodiments, the other outlet is connected to a precursor chemical recovery arrangement.

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In certain example embodiments, the pulsing valve is embedded into or attached to a structure selected from a group comprising: a structure leading to a reaction chamber, a reaction chamber structure, a reaction chamber wall, and a reaction chamber lid. In certain example embodiments, there are a plurality of pulsing valves embedded into or attached to a plurality of structures selected from a group comprising: a reaction chamber structure, a reaction chamber wall, and a reaction chamber lid.

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Accordingly, in certain example embodiments, the pulsing valve is positioned inside or at least partly inside of the reaction chamber structure or wall. In certain example embodiments, a reaction chamber structure is a structure defining the reaction chamber, such as a reaction chamber wall or lid.

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In certain example embodiments, the apparatus comprises a plurality of additional cleaning chemical inlets at the reaction chamber side of the closure to purge the closure. In yet further example embodiments, the closure is a non-completely closing member thereby not closing the route from the reactive chemical inlet to the reaction chamber outlet completely when being in closed configuration.

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In certain the pulsing valve connects to the reaction space without there being a pipeline in between. In certain example embodiments, the pulsing valve opens directly into the reaction space defined by the reaction chamber. In certain example embodiments, the pulsing valve reaction chamber outlet directly connects to inside of the reaction space by an expansion volume, or a passage widening towards the reaction space, and/or by a showerhead. In certain example embodiments, the route from the route from the pulsing valve to the reaction space is without bends. In certain example embodiments, the pulsing valve is a surface part of the reaction chamber (the reaction chamber defining the reaction space

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accommodating at least one substrate).

In certain example embodiments, the apparatus is a substrate processing apparatus. In certain example embodiments, the apparatus is a deposition reactor.

- 5 In certain example embodiments, the apparatus is a chemical deposition reactor. In certain example embodiments, the apparatus is an ALD reactor.

According to a seventh example aspect there is provided a method, comprising:
supplying reactive chemical through a pulsing valve along a route extending from
10 a reactive chemical inlet to a reaction chamber outlet;
controlling the closing of the route by a pulsing valve closure; and
supplying cleaning chemical through an additional cleaning chemical inlet at the
reaction chamber side of the closure and purging the closure by the cleaning
chemical.

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In certain example embodiments, the method comprises:
purging a valve output surface provided by the closure that is pointing towards or
directly to the reaction chamber, or substrate, by cleaning chemical released from
the additional cleaning chemical inlet that is additional to the reaction chamber
20 outlet.

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In certain example embodiments, said supplying of cleaning chemical comprises
releasing cleaning chemical onto pulsing valve output surface which cleaning
chemical reacts with reactive chemicals on the surface without producing solid
25 particles.

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In certain example embodiments, the additional cleaning chemical inlet points
directly or at least obliquely to the closure and/or valve output surface.

- 30 In certain example embodiments, the method comprises providing the additional
cleaning chemical inlet in a reaction chamber outlet channel wall.

In certain example embodiments, the method comprises:

supplying the cleaning chemical from a pipe extending towards the closure and/or valve outlet surface within the reaction chamber outlet channel, the pipe providing the additional cleaning chemical inlet.

- 5 In certain example embodiments, the method comprises:
purging the closure and/or valve output surface continuously.

In certain example embodiments, the method comprises:
purging along the closure and along the reaction chamber outlet channel wall.

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In certain example embodiments, the method comprises:
heating an outer chamber around the reaction chamber.

- 15 In certain example embodiments, the method comprises:
providing a route by-passing the closure from the reactive chemical inlet to a waste line outlet that route being open in the closed configuration of the closure.

- 20 In certain example embodiments, the method comprises:
maintaining a higher pressure in a chemical waste line beginning at the waste line outlet compared to a pressure in the reaction chamber.

- 25 In certain example embodiments, the method comprises:
completely preventing or at least partly preventing reactive chemical from flowing into the chemical waste line outlet when the closure is in the open configuration.

- In certain example embodiments, the method comprises:
performing ALD deposition within the reaction chamber.

- 30 According to an eighth example aspect there is provided a valve for use in the apparatus of the sixth aspect and any of its embodiments, the valve comprising:
a reactive chemical inlet;
a reaction chamber outlet; and
a closure having an open and closed configuration to open and close, respectively,

a route from the reactive chemical inlet to the reaction chamber outlet, the valve further comprising:

an additional cleaning chemical inlet at a downstream side of the closure to purge the closure.

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Different non-binding example aspects and embodiments have been illustrated in the foregoing. The above embodiments are used merely to explain selected aspects or steps that may be utilized in implementations of the present invention. Some embodiments may be presented only with reference to certain example

10 aspects. It should be appreciated that corresponding embodiments apply to other example aspects as well. Any appropriate combinations of the embodiments may be formed.

15 BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

- 20 Fig. 1 shows a pulsing valve with its closure in a closed configuration in accordance with certain example embodiments;
- Fig. 2 shows the pulsing valve of Fig. 1 with its closure in an open configuration;
- Fig. 3 shows a pulsing valve with its closure in a closed configuration in accordance with certain other example embodiments;
- 25 Fig. 4 shows the pulsing valve of Fig. 3 with its closure in an open configuration;
- Fig. 5 shows a pulsing valve attached to a reaction chamber structure in accordance with certain example embodiments;
- 30 Fig. 6 shows a substrate processing apparatus in accordance with certain example embodiments;
- Fig. 7 shows a method according to certain example embodiments;
- Fig. 8 shows yet another example embodiment;

- Fig. 9 shows a further example embodiment in which a closure of a pulsing valve is purged;
- Fig. 10 shows the pulsing valve of Fig. 9 with its closure in an open configuration;
- 5 Fig. 11 shows a carrier gas route according to certain example embodiments;
- Fig. 12 shows yet another example embodiment in which a closure of a pulsing valve is purged;
- Fig. 13 shows the pulsing valve of Fig. 12 with its closure in an open configuration;
- 10 Fig. 14 shows a further substrate processing apparatus in accordance with certain example embodiments;
- Fig. 15 shows a block diagram of a control system in accordance with certain example embodiments;
- 15 Fig. 16 shows the substrate processing apparatus of Fig. 14 with certain modifications
- Fig. 17 shows the substrate processing apparatus equipped with certain flow control devices in accordance with certain example embodiments;
- 20 Fig. 18 shows an alternative positioning within the substrate processing apparatus;
- Fig. 19 shows yet another example embodiment in which a closure of a pulsing valve is purged;
- Fig. 20 shows the pulsing valve of Fig. 19 with its closure in an open configuration;
- 25 Fig. 21 shows certain details of a pulsing valve in accordance with certain example embodiments;
- Fig. 22 shows a further design of the valve of Figs. 19 and 20;
- Fig. 23 shows yet another embodiment; and
- 30 Fig. 24 shows a method according to certain example embodiments.

DETAILED DESCRIPTION

In the following description, Atomic Layer Deposition (ALD) technology is used as an example. However, the invention is not limited to ALD technology, but it can be exploited in a wide variety of substrate processing apparatuses, for example, in
5 Chemical Vapor Deposition (CVD) reactors.

The basics of an ALD growth mechanism are known to a skilled person. ALD is a special chemical deposition method based on the sequential introduction of at least two reactive precursor species to at least one substrate. It is to be
10 understood, however, that one of these reactive precursors can be substituted by energy when using, for example, photon-enhanced ALD or plasma-assisted ALD, for example PEALD, leading to single precursor ALD processes. For example, deposition of a pure element, such as metal, requires only one precursor. Binary compounds, such as oxides can be created with one precursor chemical when the
15 precursor chemical contains both of the elements of the binary material to be deposited. Thin films grown by ALD are dense, pinhole free and have uniform thickness.

The at least one substrate is typically exposed to temporally separated precursor
20 pulses in a reaction vessel to deposit material on the substrate surfaces by sequential self-saturating surface reactions. In the context of this application, the term ALD comprises all applicable ALD based techniques and any equivalent or closely related technologies, such as, for example the following ALD sub-types: MLD (Molecular Layer Deposition) plasma-assisted ALD, for example PEALD
25 (Plasma Enhanced Atomic Layer Deposition) and photon-enhanced Atomic Layer Deposition (known also as flash enhanced ALD).

A basic ALD deposition cycle consists of four sequential steps: pulse A, purge A, pulse B and purge B. Pulse A consists of a first precursor vapor and pulse B of
30 another precursor vapor. Inactive gas and a vacuum pump are typically used for purging gaseous reaction by-products and the residual reactant molecules from the reaction space during purge A and purge B. A deposition sequence comprises at least one deposition cycle. Deposition cycles are repeated until the deposition

sequence has produced a thin film or coating of desired thickness. Deposition cycles can also be either simpler or more complex. For example, the cycles can include three or more reactant vapor pulses separated by purging steps, or certain purge steps can be omitted. All these deposition cycles form a timed deposition
5 sequence that is controlled by a logic unit or a microprocessor.

A reaction space is a defined volume within a reaction chamber. The desired chemical reactions occur in the reaction space. Basic ALD inlet tools through which chemicals are flown into the reaction space are generally known as shower
10 heads. The inlet of precursor chemical can be from the top, or cross flow, where the chemical is inlet from at least one side.

Fig. 1 shows a pulsing valve with its closure in a closed configuration in accordance with certain example embodiments. The pulsing valve 100 comprises
15 a valve body 110 having an inlet 101 for reactive chemical, such as a precursor chemical, and an outlet 104 towards a reaction chamber (not shown in Fig. 1). A closure 111 comprised by the pulsing valve has an open and closed configuration to open and close, respectively, a route from the reactive chemical inlet 101 to the reaction chamber outlet 104. Fig. 1 shows the closure 111 in its closed
20 configuration.

A surface of the closure 111 pointing towards the reaction chamber is defined as a valve output surface 112. The pulsing valve 100 further comprises an additional cleaning chemical inlet 103 at the reaction chamber side of the closure 111 to
25 purge the closure 111, especially the valve output surface 112, to prevent or minimize material growth thereon thus providing a cleaning effect. The same effect is achieved on side walls of the outlet (or outlet channel, or opening) 104 when the cleaning chemical exits along the side walls towards the reaction chamber. In certain example embodiments, the cleaning chemical inlet 103 is implemented
30 through the side wall of the outlet 104. A cleaning chemical inlet pipe or channel travelling within the valve body passes through the side wall and points towards the closure 111 and/or valve output surface 112.

The cleaning chemical can be the same gas that is used as the purging gas in the reaction chamber during process stage. Cleaning chemical is led to inlet 103 via a route that is separate from the routes the other chemicals use. In certain example embodiments, the cleaning chemical route has pulsing control, mass flow control, and/or valve control to change and/or limit the flow of cleaning chemical with respect to pulses in process stage.

The pulsing valve 100 further comprises an optional chemical waste line outlet 102. A route by-passing the closure 111 is formed from the reactive chemical inlet 101 to the waste line outlet 102.

The pulsing valve 100 may be attached to and/or sealed with a reaction chamber structure of a substrate processing apparatus at its attaching surface 115.

Fig. 2 shows the pulsing valve 100 with its closure 111 in an open configuration. The reactive chemical flows from the reactive chemical inlet 101 to the reaction chamber outlet 104.

Fig. 3 shows a pulsing valve with its closure in a closed configuration in accordance with certain other example embodiments. The pulsing valve 300 comprises a valve body 110 having an inlet 101 for reactive chemical, such as a precursor chemical, and an outlet 104 towards a reaction chamber (not shown in Fig. 3). A closure 111 comprised by the pulsing valve has an open and closed configuration to open and close, respectively, a route from the reactive chemical inlet 101 to the reaction chamber outlet 104. Fig. 3 shows the closure 111 in its closed configuration.

A surface of the closure 111 pointing towards the reaction chamber is, again, defined as a valve output surface 112. The pulsing valve 300 further comprises an additional cleaning chemical inlet 303 at the reaction chamber side of the closure 111 to purge the closure 111, especially the valve output surface 112, to prevent or minimize material growth thereon thus providing a cleaning effect. The same effect is achieved on side walls of the outlet (or outlet channel, or opening) 104

when the cleaning chemical exits along the side walls towards the reaction chamber. In certain example embodiments, the cleaning chemical inlet 103 is implemented as a separate pipeline extending within the outlet 104 towards the closure 111 and/or valve output surface 112.

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The pulsing valve 300 further comprises an optional chemical waste line outlet 102. A route by-passing the closure 111 is formed from the reactive chemical inlet 101 to the waste line outlet 102.

10 The pulsing valve 300 may be attached to a reaction chamber structure of a substrate processing apparatus at its attaching surface 115. As to the operation of the pulsing valve 300 a reference is made to the preceding description in connection with pulsing valve 100.

15 Fig. 4 shows the pulsing valve 300 with its closure 111 in an open configuration. The reactive chemical flows from the reactive chemical inlet 101 to the reaction chamber outlet 104.

Fig. 5 shows a pulsing valve attached to a reaction chamber structure in accordance with certain example embodiments. The pulsing valve 100 (300) may form part of the surface of the reaction chamber. In certain example embodiments, the reaction chamber structure 520 comprises a recess into which the pulsing valve 100 (300, similarly) is embedded. The pulsing valve 100 (300) may be tightened against the structure 520 at the attaching surface 115. In certain
20 example embodiments, the pulsing valve is attached to a reaction chamber wall. In certain example embodiments, the pulsing valve is attached to a reaction chamber side wall. Fig. 5 specifically shows an embodiment in which the pulsing valve is embedded into reaction chamber upper wall, or lid.

25 In certain example embodiments, the pulsing valve forms an integral part of the reaction chamber. In other example embodiments, the pulsing valve is attached to a pipe or other structure leading to a reaction chamber.

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Fig. 5 further shows by arrows certain routing alternatives to implement a route of the cleaning chemical inlet pipe (or channel). The pipe can for part of the valve structure and/or the reaction chamber lid and/or wall structure, or it can be a separate pipe attached to or through the reaction chamber lid/wall. The route can extend in parallel of the reaction chamber lid or wall structure on the outside of the structure, and/or it can penetrate through the structure into the reaction chamber side of the structure, and/or it can extend within the lid or wall structure and/or within the valve body. The other pipings, such as the reactive chemical in-feed piping, can be implemented similarly.

Fig. 6 shows a substrate processing apparatus in accordance with certain example embodiments. The substrate processing apparatus 500 comprises a reaction chamber 530 configured to house a substrate 600 within a reaction space 521 defined by the reaction chamber 530. In certain example embodiments, the apparatus comprises an outer chamber 540 surrounding the reaction chamber 530 thereby closing an intermediate space 522 in between the reaction chamber 530 and the outer chamber 540. In certain example embodiments, the intermediate space 522 is heated by a heater 545 positioned in the space 522.

A reactive chemical in-feed line 501 (which may contain a plurality of pipes) extends from a reactive chemical source (not shown) via the intermediate space (if any) to the reactive chemical inlet (see Figs. 1-4, inlet 101) of the pulsing valve 100. A chemical waste line 502 extends from the chemical waste line outlet (see Figs. 1-4, outlet 102) of the pulsing valve 100 via the intermediate space (if any) to exhaust. The waste line 502 in certain example embodiments joins to an exhaust line 555 that extends from the reaction chamber 530 to a vacuum pump (not shown).

The pulsing valve 100 has similar structure and operation as described in connection of Figs. 1 and 2. Accordingly, the pulsing valve 100 comprises a valve body having an inlet for reactive chemical, and an outlet towards the reaction chamber 530. A closure comprised by the pulsing valve has an open and closed configuration to open and close, respectively, a route from the reactive chemical

inlet to the reaction chamber outlet. The pulsing valve 100 further comprises the additional cleaning chemical inlet at the reaction chamber side of the closure to purge the closure. The pulsing valve 100 further comprises the optional chemical waste line outlet. A route by-passing the closure is formed from the in-feed line
5 501 via the reactive chemical inlet to the waste line 502 via the waste line outlet.

Although there is only one pulsing valve shown in Fig. 6 it is clear that there may be a plurality of pulsing valves with similar structural and operational features, and/or one or more other pulsing valves with different known structures. Instead of
10 the pulsing valve 100, the pulsing valve(s) 300 described in connection with Figs. 3 and 4 may be used. The pulsing valve(s) may be positioned at the side wall of the reaction chamber 530, as illustrated by reference numeral 100', or they may be positioned at the lid structure or upper wall 520, or both at the side wall and at the lid structure/upper wall 520. In certain example embodiments, at least one pulsing
15 valve can be positioned inside of the reaction chamber 530. In certain example embodiments, all of the one or more pulsing valves are positioned at the side wall and the reaction chamber is open from the top to receive energy needed in surface reactions at the substrate surface from the top, wherein the energy may be in the form of plasma or photons, for example.

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In certain example embodiments, the reaction chamber 530 comprises a hatch 531 at its side wall for loading and unloading substrates. The structure 520 may be a fixed chamber upper wall or a removable lid. In certain example embodiments, the structure 520 is a removable lid. The substrate or substrates 600 are loaded
25 from the top side of the reaction chamber by lifting the lid 520. A preferred position of the pulsing valve(s) is then at the side wall. In the event the removable lid has pulsing valve(s) at the lid, the pipings 501 and 502 can be designed to connect and disconnect if needed, for example at line 560 in Fig. 6. In certain example embodiments, the reaction chamber 520 is lowered, for example, by a bellows
30 structure 570 to form a substrate loading route in between the chamber 530 and lid 520. A similar arrangement has been described in a co-pending international application PCT/FI2017/050071 filed by the same application. This enables loading from the side of the reaction chamber.

Fig. 7 shows a method according to certain example embodiments. In step 701, reactive chemical is supplied to a reaction chamber via a pulsing valve for deposition. The supply of reactive chemical to the reaction chamber is interrupted
5 in step 702. The valve output surface is purged by cleaning chemical, and the purging by cleaning chemical is continued in step 703.

In certain example embodiments, a reactive chemical pulse into the reaction chamber is followed by a cleaning chemical period. The cleaning chemical may be
10 gas or fluid. In certain example embodiments, the cleaning chemical flows continuously. In certain example embodiments, the flow rate of cleaning chemical is reduced at least during a part of a precursor chemical pulse. In certain example embodiments, the cleaning chemical flows at an elevated rate during a period in which precursor vapor is not released into the reaction chamber via the pulsing
15 valve in question.

The cleaning chemical can refer here to a gas or fluid, which can push fluid atoms or molecules away from a space, and/or which can remove them from surfaces. The cleaning chemical can be neutral, such as argon gas Ar, or nitrogen gas N₂,
20 or reactive, such as heated gas, or ionized or radical gas. It can be any such gas which does not react with the reactive chemical, or it can be any such gas which reacts with the chemical to be cleaned in a way that it does not produce solid species (or in some cases neither liquid species, which would react with the substrate). In certain example embodiments, the cleaning gas can be helium gas
25 He. Some or all of the gases can be considered as carrier gases.

In certain or all foregoing embodiments, the following applies:

- chemical flowing into the inlet 101 may consist of pure precursor (or reactive)
30 chemical, or a mixture of precursor chemical and carrier gas;
- the flow and mixing of reactive gas to carrier gas can be controller with mass flow controller or valves synchronized with the whole process, or with any synchronization down to duration of a step of the deposition cycle, such as

presented, for example, in US patent 8,211,235 assigned to the same assignee;

- the pulsing valve 100 or 300 may contain a flow restrictor, such as a capillary, in the optional waste line 502 within the valve area;

- the valve 100 or 300 may be a 3-way valve or a 4-way valve in which a fluid flow hits the closure 111;

- the fluid flow may be released from the additional cleaning chemical inlet positioned at a side of the valve (as in Figs. 1 and 2), and/or the additional cleaning chemical inlet may be provided by a cleaning chemical inlet pipe coming from the outside of valve body (as in Figs. 3 and 4);

- the cleaning chemical inlet pipe may be heated, which heat may be higher than the reaction chamber heat;

- the cleaning chemical inlet pipe may be provided with pre-heated gas;

- the provided reaction chamber outlet channel (or opening) 104 towards the reaction chamber may be the only inlet to the reaction chamber (i.e., there are no other gas inlets to the reaction chamber) – this outlet channel may provide all chemicals needed in the reactions within the reaction chamber;

- the pulsing valve may be oriented such that the closure 111 faces (or sees) the reaction space (or substrate surface);

- the opening may expand from the closure surface towards the reaction chamber

- the expansion may be in the form of a conical opening;

- the pulsing valve may form part of the reaction chamber (or reaction vessel) structure – the reaction chamber structure may be a reaction chamber lid

- the pressure in the intermediate space 522 pressure may be 1000-0.1 mBar, preferably 100-1 mBar, more preferably 20-2 mBar.

- the reaction chamber pressure may be ambient to 1 μ Bar, more preferably 10-0.01 mBar, most preferably 1-0.1 mBar.

- the reaction chamber pressure can be varied with the aid of modifying the vacuum in foreline (exhaust line) 555 leading out from the chamber 530, or by a total gas flow to the reaction space 521, and possibly intermediate space 522;

- the reaction chamber pressure referred here can be synchronized with the whole process, or any synchronization down to duration of a step of the deposition cycle may be applied

Fig. 8 shows yet another example embodiment. The closure 111 can be configured to close the waste line outlet 102', or at least partly close the waste line outlet 102', or decrease the flow to the waste line, while the route from the reactive chemical inlet 101 to the reaction chamber outlet 104 is opened. The waste line outlet 102' may be positioned at the other side of the closure 111 so that when the closure 111 moves away from the reaction chamber outlet 104 it pushes against the waste line outlet (opening) 102'.

Yet in other embodiments, in a slightly modified valve design, the closure 111 will close the reactive chemical inlet (opening) 101 while it closes the passage to the reaction chamber, e.g., by pushing against the inlet 101. This is in order to evacuate reactive gas from the space above the closure 111 into the waste line. This is especially applicable if the closure 111 is not able to completely block the reactive chemical flow into the reaction chamber past the closure (i.e., when the closure 111 is not completely closing). The pressure in the space above the closure 111 is then lower compared to the pressure inside the reaction chamber and residual reactive chemical flows into the direction of the waste line.

The description concerning any particular preceding embodiment is directly applicable to other disclosed embodiments. This applies both with regard to the structure and operation of the disclosed apparatus.

Without limiting the scope and interpretation of the patent claims, certain technical effects of one or more of the example embodiments disclosed herein are listed in the following. A technical effect is providing a minimum amount of trapped precursor chemical thereby avoiding undesired particle generation, while enabling high pulsing speed, for example, more than one pulse and purge per second. Another technical effect is a mechanically smaller pulsing valve implementation, for example, less than 10 cm³, such as 4 cm³. Another technical effect is a cleaning effect by purging reactive material away from surfaces. Undesired gas phase reactions of material adsorbed on solid surfaces of the pulsing valve structure and pulsing valve outlet can be minimized.

It should be noted that some of the functions or method steps discussed in the preceding may be performed in a different order and/or concurrently with each other. Furthermore, one or more of the above-described functions or method steps may be optional or may be combined.

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In the foregoing drawings 1-4, and 8 a space inside the valve 100 or 300 where the closure 111 is moved should in each case be consider to be a closed volume.

What has been described in the preceding concerning the embodiments shown in
10 Figs. 1-8 generally apply also for the following embodiments. Also, what will be described in connection with any of the following embodiments generally apply to the other followings embodiments as well as for the embodiments shown and described in the preceding.

15 Fig. 9 shows a further example embodiment in which a closure of a pulsing valve is purged. The pulsing valve 900 comprises a valve body 910 having an inlet 901 for reactive chemical, such as a precursor chemical, and an outlet 904 towards a reaction chamber (reaction chamber not shown in Fig. 9). A closure 191 comprised by the pulsing valve 900 has an open and closed configuration to open
20 and close, respectively, a route from the reactive chemical inlet 901 to the reaction chamber outlet 904. Fig. 9 shows the closure 191 in its closed configuration.

The pulsing valve 900 further comprises an additional flow channel inlet or outlet to purge the closure. In Fig. 9 is shown an additional flow channel outlet 903. The
25 outlet 903 is at the same side of the closure 191 as the reactive chemical inlet 901. In this embodiment, the outlet (or pipe end) 903 forms a starting point of a waste line bypassing the reaction chamber. The waste line may extend, for example, to a particle trap or vacuum pump (not shown).

30 The flow channel or outlet 903 is positioned to reside within a flow channel providing the reactive chemical inlet 901. Accordingly, the outlet pipe 903 has a cross-sectional flow area that is smaller than the corresponding cross-sectional flow area of the flow channel (inlet pipe) providing the reactive chemical inlet 901.

In an embodiment, the flow channel or outlet 903 has a cross-sectional flow area that is less than 25 % of the cross-sectional flow area of the surrounding flow channel providing the reactive chemical inlet 901.

- 5 In the closed configuration of the closure 191, reactive chemical from the reactive chemical inlet 901 flows to purge the closure 191 on its way from the reactive chemical inlet 901 to the waste channel outlet 903 of the valve. The flow direction of the purge is along the surface of the closure.
- 10 The pulsing valve 900 may further comprise a carrier gas inlet 911 in fluid communication (via the closure 191) with the reaction chamber outlet 904. When the closure 191 is in its closed configuration, the closure 191 rests on the reactive chemical inlet 901, or on a closure sealing ring (not shown), closing the route from the reactive chemical inlet 901 to the reaction chamber outlet 904. At the same
- 15 time this arrangement provides for a curved route (see Fig. 11) from inlet 911 to outlet 904 in between the closure 191 and the valve body 910. Carrier gas/inactive gas flowing along this route purges the closure 191 at an area around the area of the reactive chemical inlet 901.
- 20 Fig. 10 shows the pulsing valve 900 with its closure 191 in an open configuration. The reactive chemical flows from the reactive chemical inlet 901 to the reaction chamber outlet 904. Depending on the embodiment, the reactive chemical is mixed with a carrier gas arriving from inlet 911. A suction into the additional flow channel outlet 903 is maintained to prevent reactive chemical from stagnating
- 25 therein.

Fig. 11 shows the fluid communication path of carrier (or inactive) gas from the inlet 911 to outlet 904. The route is open during an entire deposition cycle or sequence with the difference that when the closure 191 is in its closed configuration the route bypasses the reactive chemical inlet area and when the

30 closure 191 is in its open configuration the carrier gas flow purges the entire area of the closure 191. The route may be implemented by a toroidal shaped flow path ("a donut ring structure") around the closure 191.

Fig. 12 shows a further example embodiment in which a closure of a pulsing valve is purged. The pulsing valve 900' otherwise corresponds to the structure and operation of the pulsing valve 900 except that it is the reactive chemical inlet pipe 901' that resides within the flow channel (waste line) 903', and not *vice versa*. Accordingly, in this embodiment, the valve body 910 provides the waste line outlet 903' and the reactive chemical inlet pipe 901' is the smaller pipe positioned within the outlet pipe 903'.

Fig. 12 shows the valve closure 191 in its closed configuration. In the closed configuration of the closure 191, reactive chemical from the reactive chemical inlet 901' flows to purge the closure 191 on its way from the reactive chemical inlet 901' to the flow channel 903' (waste line outlet of the valve 900').

Fig. 13 shows the pulsing valve 900' with its closure 191 in an open configuration. The reactive chemical flows from the reactive chemical inlet 901' to the reaction chamber outlet 904. Depending on the embodiment, the reactive chemical is mixed with a carrier gas arriving from inlet 911. A suction into the waste line 903' is maintained to prevent reactive chemical from stagnating in the line.

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Fig. 14 shows a further substrate processing apparatus in accordance with certain example embodiments. The substrate processing apparatus 1400 comprises a reaction chamber 1430 configured to house a substrate 600 within a reaction space 1421 defined by the reaction chamber 1430. In certain example embodiments, the apparatus comprises an outer chamber 1440 surrounding the reaction chamber 1430 thereby closing an intermediate space 1422 in between the reaction chamber 1430 and the outer chamber 1440. In certain example embodiments, the intermediate space 1422 is heated by a heater 1445 positioned in the space 1422.

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The pulsing valve 900, acting as a hot valve, is positioned within the heated intermediate space 1422. A reactive chemical in-feed line 1401 extends from a reactive chemical source (not shown) to the reactive chemical inlet 901 of the

pulsing valve 900. A waste line 1402 begins at the waste line outlet 903 of the pulsing valve 900, and it extends via the intermediate space 1422 to exhaust. The waste line 1402 in certain example embodiments joins to an exhaust line 1455 that extends from the reaction chamber 1430 to a vacuum pump (not shown). In other
5 embodiments, the waste line 1402 instead extends to a chemical extraction with the aid of separate means creating vacuum for the line (not shown).

The pulsing valve 900 has similar structure and operation as described in connection of Figs. 9-11. Accordingly, the pulsing valve 900 comprises a valve
10 body having an inlet 911 for carrier gas arriving from a carrier gas line 1403. The pulsing valve further has an outlet 904 through which inactive gas or a mixture of carrier gas and pulsed reactive chemical (depending on the processing cycle phase) flow along a reaction chamber in-feed line 1404 towards the reaction chamber 1430. A closure comprised by the pulsing valve has an open and closed
15 configuration to open and close, respectively, a route from the reactive chemical inlet 901 to the reaction chamber outlet 904. The reaction chamber in-feed line 1404 may end up to the upper wall or lid 1420 of the reaction chamber 1430 wherefrom the fluid that flows therein is delivered into the interior of the reaction chamber 1430. In certain example embodiments, as shown in Fig. 14, the in-feed
20 line 1404 is routed to travel along the side wall of the reaction chamber 1430 into an attachment point. A metal-metal contact may be provided at the attachment point allowing a discontinuation of the in-feed line 1404 when the reaction chamber lid 1420 is lifted at line 1460 for top-loading a substrate into the reaction chamber 1430.

25 Fig. 14 further shows an actuating element 1480 of the pulsing valve 900. The actuating element 1480 causes movement of the closure 191 to provide the open and closed configurations of the closure 191. The actuating element 1480 can be located inside or outside of the heated and/or vacuum intermediate space 1422. In
30 the event the actuating element is located outside, actuation may be guided to the valve 900 by such methods as a mechanical bar, pneumatic means, hydraulic means, or magnet. In certain example embodiments, the actuating element 1480 receives instructions in the form of signals from a control system 1450 that

controls the operation of the apparatus 1400. The control system 1450 (see Fig. 15) comprises at least one processor 1451 to control the operation of the apparatus 1400 and at least one memory 1452 comprising a computer program or software 1453. The software 1453 includes instructions or a program code to be
5 executed by the at least one processor 1451 to control the apparatus 1400. The software 1453 may typically comprise an operating system and different applications.

The at least one memory 1451 may form part of the apparatus 1400 or it may
10 comprise an attachable module. The control system 1450 further comprises at least one communication unit 1454. The communication unit 1454 provides for an interface for internal communication of the apparatus 1400. In certain example embodiments, the control unit 1450 uses the communication unit 1454 to send instructions or commands to and to receive data from different parts of the
15 apparatus 1400, for example, measuring and control devices, valves, pumps, and heaters.

The control system 1450 may further comprise a user interface 1456 to co-operate with a user, for example, to receive input such as process parameters from the
20 user.

As to the operation of the apparatus 1400, the control system 1450 controls e.g. the process timings of the apparatus. In certain example embodiments, the apparatus 1400 is configured, by means of being programmed, for example, to
25 purge, during the entire substrate processing cycle or sequence, all surface areas of the closure exposed to processing gases. In particular, this may be interpreted to contain all open (i.e., non-covered) areas of the closure that are exposed to a precursor gas flow at least during certain periods of the deposition cycle or sequence. These open areas include exposed areas that are not contacted by any
30 fixed part of the valve 900.

In certain example embodiments, the apparatus 1400 is programmed to purge the closure at the area of the reactive chemical inlet 901 continuously by said reactive

chemical during the entire substrate processing cycle or sequence, and purge the closure around that area continuously by carrier gas.

5 In certain example embodiments, the apparatus 1400 is programmed to provide the channel 1402, which can also be denoted as a suction channel, with suction during the entire substrate processing cycle or sequence. Furthermore, the apparatus in certain example embodiments is programmed to provide a gas flow within the reactive chemical in-feed line 1401 during the entire substrate processing cycle or sequence. The apparatus 1400 is thus programmed to purge
10 the closure at the area of the reactive chemical inlet 901 during the entire substrate processing cycle or sequence, this purge being by reactive gas in certain embodiments.

15 In certain example embodiments, the apparatus is programmed to pulse reactive chemical into a carrier gas flow that is configured to flow from the inlet 911 to the outlet 904.

20 In certain example embodiments, said continuous purge of the closure does not occur through the additional flow channel (waste line) 1402 or does not occur through the additional flow channel 1402 during the entire substrate processing cycle or sequence. For example, when the closure is in the open configuration, the purge in certain example embodiments is implemented from the inlet(s) 901, 911 to the reaction chamber outlet. In certain example embodiments, the additional flow channel 1402 is closed or at least partially closed when the closure is in the
25 open configuration.

In certain example embodiments, the flow into the waste line 1402 is reduced but not stopped during the periods in which the closure is in its open configuration.

30 Each flow channel may contain its own pulsing control, pressure control, mass flow control, and/or valve control to change and/or limit the flow within the flow channel concerned. Depending on static or dynamic flows or pressure, those flow control means may be used to ensure the desired flow direction of one or any

channel in the apparatus or valve.

Although there is only one pulsing valve shown in Fig. 14 it is clear that there may be a plurality of pulsing valves with similar structural and operational features, and/or one or more other pulsing valves with different known structures.

Fig. 16 shows a substrate processing apparatus 1600 containing certain modifications to the substrate processing apparatus 1400. Instead of the pulsing valve 900, the pulsing valve(s) 900' described in connection with Figs. 12 and 13 may be used. Instead of or in addition to attaching the pulsing valves in free portions of the in-feed lines the pulsing valve(s) may alternatively be positioned at the side wall of the reaction chamber 1430, as illustrated by reference numeral 900*, or they may be positioned at the lid structure or upper wall 1420, or both at the side wall and at the lid structure/upper wall 1420. Further, in certain example embodiments, at least one pulsing valve can be positioned inside of the reaction chamber 1430. In certain example embodiments, all of the one or more pulsing valves are positioned at the side wall and/or in the free portions in between of the chambers 1430 and 1440, and the reaction chamber 1430 is open from the top to receive energy needed in surface reactions at the substrate surface from the top, wherein the energy may be in the form of plasma or photons, for example.

In certain example embodiments, the reaction chamber 1430 comprises a hatch 1431 at its side wall for loading and unloading substrates. The structure 1420 may be a fixed chamber upper wall or a removable lid. In certain example embodiments, the structure 1420 is a removable lid. The substrate or substrates 600 are loaded from the top side of the reaction chamber by lifting the lid 1420. A preferred position of the pulsing valve(s) is then at the side wall or in the free portions of the in-feed lines. In the event the removable lid has pulsing valve(s) at the lid, the pipings 1401, 1402 etc. can be designed to connect and disconnect if needed, for example at line 1460 in Fig. 16. In certain example embodiments, the reaction chamber 1430 is lowered, for example, by a bellows structure 1470 to form a substrate loading route in between the chamber 1430 and lid 1420. A similar arrangement has been described in a co-pending international application

PCT/FI2017/050071 filed by the same application. This enables loading from the side of the reaction chamber.

In the presented embodiments there can be means to adjust or limit flow with flow control devices (or arrangements) in any of the presented lines or flow channels. Examples of such devices are valves, mass flow controllers, ALD valves, non-completely closing valves, multi-stage digital valves and valves with parallel of routes with a restricted gas flow, for example. These devices operate under the control of the control system 1450. The presented lines or flow channels may also comprise pressure indicators if needed, for example, in the reactive chemical in-feed line 1401.

In some embodiments, the closure 991 has a steady (constant) configuration, whereupon fluid flow via the pulse valve is adjusted with the aid of flow controlling elements positioned in flow channels in fluid communication with the pulsing valve. The term "steady" is utilized hereby to indicate the closure whose configuration remains constant during operation, thereby the open and closed configurations are not provided.

Fig. 17 shows the substrate processing apparatus equipped with certain flow control devices in accordance with certain example embodiments. The substrate processing apparatus 1700 shown in Fig. 17 is generally of the type described in connection with Fig. 14 or 16. It comprises the hot valve type of pulsing valve 900 positioned within the heated intermediate space.

The reactive chemical in-feed line 1401 comprises at least one flow control device 1 to control the flow from a reactive chemical source (not shown) to the valve 900. The at least one flow control device comprises a valve controlled by the control system 1450. In certain example embodiments, the valve is located in connection with the source. The at least one flow control device 1 may additionally comprise a mass flow controller controlled by the control system 1450.

Similarly, the carrier gas line 1403 comprises at least one flow control device 3 to

control the flow from a carrier gas (or inactive gas) source (not shown) to the valve 900. The at least one flow control device comprises a valve controlled by the control system 1450. In certain example embodiments, the valve is located in connection with the carrier gas source. The at least one flow control device 3 may
5 additionally comprise a mass flow controller controlled by the control system 1450.

In certain example embodiments, the waste line 1402 comprises at least one flow control device 2 to control outgoing flow from the valve 900. The at least one flow control device 2 is controlled by the control system 1450. In certain example
10 embodiments, the control system 1450 is programmed to allow a precursor chemical to flow along the waste line 1402 via the at least one flow control device 2 during an entire substrate processing cycle or sequence, such as a vacuum deposition cycle or a vacuum deposition sequence. In certain example
15 embodiments, the control system 1450 is programmed to restrict the flow in the waste line 1402 during a period in which the reactive chemical is desired to be present in the reaction chamber 1430 (for example, during the precursor vapor pulse period of the precursor in question). During this time the flow of the precursor chemical or vapor in question into the waste line 1402 is reduced but not completely stopped to avoid stagnation.

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The exhaust line 1455 may also have at least one flow controlling device 5 controlled by the control system 1450. The reaction chamber in-feed line 1404 may also have at least one flow controlling device (although not shown in Fig. 17) controlled by the control system 1450.

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Further embodiments include use of the valve 900, etc. outside or at least partially outside of the reaction and/or vacuum chambers 1430 and 1440 as shown in Fig. 18. There can be heated inlet line(s) extending all the way from a source (not shown) to the reaction chamber 1430. The line(s) can be heated from the outside
30 or from the inside, as presented for example in US 8,741,062 B2. The heated area on the outside of the heated chambers 1430 and 1440 is denoted by reference numeral 180. Further the valve 900, etc. located outside of the vacuum chamber 1440 can have a separate heating in a manner presented in the said prior art

patent publication.

Fig. 19 shows yet another example embodiment in which a closure of a pulsing valve is purged. The pulsing valve 900" comprises a valve body 910 having an inlet 901" for reactive chemical, such as a precursor chemical, and an outlet 904" towards a reaction chamber (reaction chamber not shown in Fig. 19). A closure 191 comprised by the pulsing valve 900" has an open and closed configuration to open and close, respectively, a route from the reactive chemical inlet 901" to the reaction chamber outlet 904". Fig. 19 shows the closure 191 in its closed configuration.

The pulsing valve 900" further comprises an additional flow channel outlet to purge the closure. In Fig. 19 is shown a waste channel outlet 903". The outlet 903" is at the same side of the closure 191 as the reactive chemical inlet 901". This means that when the closure is in its closed configuration the inlet 901" and outlet 903" are in fluid communication, but the flow from inlet 901" and outlet 903" to the outlet 904" is prevented (by the closure 191 that covers an opening separating the two sides of the valve 900"). The inlet 901" is in fluid communication with the outlet 903" in a similar manner as the inlet 911 was in fluid communication with the outlet 904 through the curved route (toroidal shaped flow path) in the embodiment shown in Figs. 11 and 12.

In the closed configuration of the closure 191, gas from the reactive chemical inlet 901" thus flows to purge the closure 191 (on the reactive chemical side of the opening) on its way from the reactive chemical inlet 901" to the waste channel outlet 903" of the valve. The flow direction of the purge is along the surface of the closure.

The pulsing valve 900" in certain example embodiments further comprises a carrier gas inlet 911" in fluid communication (via the closure 191) with the reaction chamber outlet 904". A flow channel providing the carrier gas inlet 911" approaches the closure at an oblique angle taking a turn at the closure and continuing towards the reaction chamber (and providing the reaction chamber

outlet 904" of the valve). The channel may therefore be an L-shaped channel. In a preferred embodiment, the flow from the pulsing valve to the reaction chamber is unrestricted. The flow path from the pulsing valve to the reaction chamber is realized without any intermediate flow restricting elements such as a valve or a filter.

When the closure 191 is in its closed configuration, the closure 191 rests on a closure sealing ring 1905 and closes the route from the reactive chemical inlet 901" to the reaction chamber outlet 904". The surface of the closure on the carrier gas inlet and reaction chamber outlet side (of the opening or sealing ring 1905) is purged by carrier gas (or inactive gas) arriving from the carrier gas inlet 911". The closure on the other side of the opening or sealing ring 1905 (i.e., on the reactive chemical inlet and waste line outlet side) is purged by reactive and/or carrier gas as described in the preceding).

Fig. 20 shows the pulsing valve 900" with its closure 191 in an open configuration. The reactive chemical flows from the reactive chemical inlet 901" to the reaction chamber outlet 904". Depending on the embodiment, the reactive chemical is mixed with a carrier gas (inactive gas) arriving from inlet 911". In addition, the reactive chemical itself may be a mixture of reactive chemical and carrier gas when arriving at the reactive chemical inlet 901" (which applies to other embodiments as well). A suction into the waste channel outlet 903" is maintained to prevent reactive chemical from stagnating therein. The flow geometry of the reactive chemical is such that the turn along the route from the reactive chemical inlet 901" to the reaction chamber outlet 904" is less sharp than the turn along the route from the carrier gas inlet 911" to the reactive chemical outlet 904" to provide a minimum flow barrier for the reactive chemical.

The waste line beginning at the waste channel outlet 903" in the embodiments shown in Figs. 19 and 20 optionally comprises at least one flow control device 2 to control outgoing flow from the valve 900". The at least one flow control device 2 is controlled by the control system 1450. In certain example embodiments, the control system 1450 is programmed to allow a precursor chemical to flow along

the waste line via the at least one flow control device 2 during an entire substrate processing cycle or sequence, such as a vacuum deposition cycle or a vacuum deposition sequence. In certain example embodiments, the control system 1450 is programmed to restrict the flow in the waste line during a period in which the reactive chemical is desired to be present in the reaction chamber 1430 (for example, during the precursor vapor pulse period of the precursor in question). During this time the flow of the precursor chemical or vapor in question into the waste line is reduced but not completely stopped to avoid stagnation.

- 10 In certain implementations, the flow channel providing the carrier gas inlet 911" and reaction chamber outlet 904" is a larger capacity channel than the flow channels providing the reactive chemical inlet 901" and waste line outlet 903".

Fig. 21 shows the three-dimensional structure allowing a toroidal shaped flow path in more detail. The curved route 21a along the structure from inlet A to outlet B is formed when the closure (not shown) rests on the sealing ring 1905 (closed configuration). The route from inlet A via the sealing ring 1905 to the other side of the ring to outlet C is formed when the closure moves away from the ring 1905 (open configuration). In certain example embodiments, the purging route 21a at least partially extends to a backside of the closure.

Fig. 22 shows a further design of the pulsing valve of Figs. 19 and 20, taking advantage of the toroidal shaped flow path shown in Fig. 21. The flow control device 2 and the control system 1450 has not been drawn in Fig. 22. The presented design differs from that shown in Figs. 19 and 20 only in that the sharp angle in the channel providing the carrier gas inlet 911" and reaction chamber outlet 904" has been replaced by a non-sharp, curved channel. What has been described concerning Figs. 19-21 apply to the embodiment shown in Fig. 22.

- 30 Fig. 22 thus shows a two-dimensional projection of the pulsing valve of Fig. 21, in which the reactive chemical inlet 901" corresponds to the inlet A in Fig. 21 and the waste line outlet 903" corresponds to the outlet B in Fig. 21, accordingly.

The actuating element 1480 moves the closure 191 so that the closure either seals or opens (broken line) the opening between the reactive chemical inlet & waste channel outlet side and the inactive (carrier) gas inlet & reaction chamber outlet side of the valve. In an embodiment, the valve body 910 is made of metal and is shown by the striped area in Fig. 22. In the closed configuration of the closure 191, the gas incoming from the inactive (carrier) gas inlet 911" continuously purges the inactive (carrier) gas inlet & reaction chamber outlet side of the closure 191 and the gas incoming from the reactive chemical inlet 901" and having the curved or toroidal flow path on the other side of the opening purges the closure 191 on the other side of the opening (i.e., purges the area of the closure 191 around the center area of the closure 191). The valve body 910 separates the curved or toroidal flow path from the channel providing the carrier gas inlet 911" and reaction chamber outlet 904". In the open configuration of the closure 191, in certain example embodiments, the gas incoming from the reactive chemical inlet 901" purges the entire surface of the closure 191 and flows mainly via the reaction chamber outlet 904" but also via the waste line outlet 903". The purging effect is supplemented by the gas incoming from the inactive (carrier) gas inlet 911". Accordingly, presented design avoids gaps that are not continuously purged.

In some embodiments, such as depicted in Figs. 21 and/or 22, for example, the pulsing valve 100, 300, 900, 900', 900", 900* is implemented without non-continuously purged gaps (or "pockets") in a meaning of the purging being independent of the state of pulsing valve. Thus, independent of said pulsing valve being open or closed, all the surfaces in the valve are subjected to the gas flow.

In certain example embodiments, instead of the open and closed configuration of the closure, there are provided an open and partially closed configuration of the closure to allow open and partially closed operation as regards the flows flowing via the valve. In certain example embodiments, there are provided an open, a partially closed and a closed configuration of the closure.

Fig. 23 shows yet another embodiment. In this embodiment, the pulsing valve is not a "pulsing valve" in its conventional meaning but another flow guiding device.

The flow guiding device 2300 is fluidly connected to the reaction chamber accommodating the substrate to be processed (not shown in Fig. 23). The flow guiding device comprises a reactive chemical inlet 901'', an outlet towards the reaction chamber (i.e., a reaction chamber outlet 904''), and a flow guiding element 991 for routing incoming gas from the reactive chemical inlet 901'' to the reaction chamber outlet 904'' or to another outlet 903'' of the device 2300. The flow guiding element 991 in this embodiment is a stationary closure. The flow guiding element 991 may be a flow divider, such as an edge, positioned at a position in which the incoming flow from the reactive chemical inlet 901'' branches into a flow towards different outlets (herein: outlets 903'' and 904'' at opposite (different) directions). Said another outlet 903'' may be a waste line outlet. The different flow directions (and entry of fluid flow into said directions) may be caused by the shape of the element 991 or by a change in the shape of the element 991. In some embodiments, the different flow directions (and entry of fluid flow into said directions) are caused by pressure differences in a flow channel junction area within the device 2300. In some embodiments, the different flow directions (and entry of fluid flow into said directions) are caused by pressure differences in a junction area where a flow channel connects the flow channel leading from the carrier gas inlet 911'' to reaction chamber outlet 904'' and said another outlet (waste channel outlet) 903''.

The device 2300 further comprises an inactive or carrier gas inlet 911''. The flow of inactive or carrier gas from the inlet 911'' towards the reaction chamber outlet 904'' is maintained during an entire substrate processing cycle or sequence.

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The substrate processing apparatus that comprises the device 2300 also comprises a control system (for example, the control system 1450). In certain example embodiments, the control system provides pressure-based control of flow rate from the reactive chemical inlet 901'' to the reaction chamber outlet 904'' and to said another outlet 903''. In certain example embodiments, the control system comprises a pressure changing device (such as a pump, mass flow controller, etc., not shown) positioned in the pipeline providing said another outlet 903'' to cause a change in pressure within the pipeline. Depending on pressure conditions within

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the device 2300, gas flowing from the reactive chemical inlet 901" flows to the outlet 903" or 904" (mixing up with inactive carrier gas flowing from inlet 911") or to both outlets 903" and 904". In certain example embodiments, if the gas flowing from the reactive chemical inlet 901" flows only to the outlet 903" the gas flowing from the inlet 911" flows also to the outlet 903" in addition to flowing to outlet 904". In that way the surfaces of the device 2300 are continuously purged (during the entire substrate processing cycle or sequence). The pressure conditions within the device are altered by said pressure changing device and possible other pressure changing devices positioned in suitable parts of the apparatus.

Fig. 24 shows a method according to certain example embodiments of the invention. In step 2401, reactive chemical is supplied to a reaction chamber via a pulsing valve/flow guiding device for substrate processing. The supply of reactive chemical to the reaction chamber is interrupted in step 2402. The purging of the closure/flow guiding element is continued in step 2403.

Without limiting the scope and interpretation of the patent claims, certain further technical effects of one or more of the example embodiments disclosed herein are listed in the following. A technical effect is providing valve surfaces having reactive gas with a continuous purge. This concerns especially those surfaces which could conduct reactive gas into the direction of the reaction chamber. A further technical effect is providing a geometry within a pulsing valve eliminating the formation of non-purged pipeline portions. A further technical effect is providing a valve connection or joint between a chemical in-feed line and a main inactive gas line with no dead space on either side of the joint/connection. A further technical effect is improving operational reliability.

The foregoing description has provided by way of non-limiting examples of particular implementations and embodiments of the invention a full and informative description of the best mode presently contemplated by the inventors for carrying out the invention. It is however clear to a person skilled in the art that the invention is not restricted to details of the embodiments presented above, but that it can be implemented in other embodiments using equivalent means without deviating from

the characteristics of the invention.

Furthermore, some of the features of the above-disclosed embodiments of this invention may be used to advantage without the corresponding use of other
5 features. As such, the foregoing description should be considered as merely illustrative of the principles of the present invention, and not in limitation thereof. Hence, the scope of the invention is only restricted by the appended patent claims.

Claims

1. An apparatus, comprising:
 - a reaction chamber (530, 1430) to accommodate a substrate (600) to be processed;
 - a pulsing valve (100, 300, 900, 900', 900'', 900*) fluidly connected to the reaction chamber (530, 1430), the pulsing valve comprising:
 - a reactive chemical inlet (101, 901, 901', 901'') to receive reactive chemical;
 - a reaction chamber outlet (104, 904, 904'') to mediate provided fluid connection of the pulsing valve to the reaction chamber (530, 1430);
 - a closure (111, 191, 991) to control fluid flow from the reactive chemical inlet (101, 901, 901', 901'') in the pulsing valve to the reaction chamber outlet (104, 904, 904''); and
 - an additional flow channel inlet or outlet (103, 303, 903, 903', 903'') at the reaction chamber side of the closure to continuously purge the closure (111, 191) through the additional flow channel during an entire substrate processing cycle or sequence.
2. The apparatus of claim 1, comprising the closure (111, 191) having an open and closed configuration to open and close, respectively, or at least partially close a route from the reactive chemical inlet (101, 901, 901', 901'') to the reaction chamber outlet (104, 904, 904'').
3. The apparatus of claim 1, comprising the closure (991) having only a steady configuration, the apparatus being configured to adjust fluid flow with the aid of flow controlling elements positioned in flow channels in fluid communication with the pulsing valve.
4. The apparatus of any preceding claim, configured to purge, during the entire substrate processing cycle or sequence, the entire surface area of the closure (111, 191) exposed to processing gases.

5. The apparatus of any preceding claim, further comprising a vacuum chamber (540, 1440) surrounding the reaction chamber (530, 1430).
- 5 6. The apparatus of claim 5, comprising the pulsing valve (100, 300, 900, 900', 900'', 900*) within the vacuum chamber (540, 1440) on the outside of the reaction chamber (530, 1430) in a heated area defined by the vacuum chamber.
- 10 7. The apparatus of any preceding claim, wherein the flow direction of the purge is along the surface of the closure (111, 191, 991).
8. The apparatus of any preceding claim, configured to purge the closure (111, 191) during the entire substrate processing cycle or sequence.
- 15 9. The apparatus of any preceding claim, comprising a suction channel (1402) on the reactive chemical inlet side of the closure (191) to enable a reactive chemical flow through the reactive chemical inlet (901, 901', 901'') to the suction channel (1402) to purge the closure (191).
- 20 10. The apparatus of claim 9, configured to provide the suction channel (1402) with suction during the entire substrate processing cycle or sequence.
- 25 11. The apparatus of any preceding claim, the pulsing valve further comprising a carrier gas inlet (911, 911'') fluidly connected to the reaction chamber via the reaction chamber outlet (904, 904'').
- 30 12. The apparatus of claim 11, configured to pulse reactive chemical into a carrier gas flow flowing from the carrier gas inlet (911) towards the reaction chamber via the reaction chamber outlet (904, 904'').
13. The apparatus of any preceding claim, wherein the pulsing valve is embedded into or forms part of a reaction chamber wall or lid (1420).

14. The apparatus of any preceding claim, wherein the additional flow channel (1402) resides within a flow channel (1401) providing the reactive chemical inlet (901).
- 5 15. The apparatus of any preceding claim, wherein the additional flow channel (1402) has a cross-sectional flow area that is less than 25 % of the cross-sectional flow area of a flow channel (1401) providing the reactive chemical inlet (901).
- 10 16. The apparatus of any preceding claim 1-13, wherein a flow channel providing the reactive chemical inlet (901') resides within the additional flow channel (903').
- 15 17. The apparatus of any preceding claim, wherein the flow path from the carrier gas inlet (911, 911'') to the reaction chamber (1430) is unrestricted.
18. The apparatus of any preceding claim, wherein the pulsing valve (100, 300, 900, 900', 900'', 900*) is implemented without non-continuously purged gaps.
- 20 19. The apparatus of any preceding claim, the pulsing valve (100, 300, 900, 900', 900'', 900*) further comprising a heating arrangement (545, 1445) configured to operate the pulsing valve at an elevated temperature.
20. A method, comprising:
- 25 supplying reactive chemical through a pulsing valve (100, 300, 900, 900', 900'', 900*) along a route extending from a reactive chemical inlet (101, 901, 901', 901'') to a reaction chamber outlet (104, 904, 904'') of the pulsing valve; controlling the closing of the route by a pulsing valve closure (111, 191); and
- 30 purging the closure (111, 191) continuously through an additional flow channel (103, 303, 1402)) at the reaction chamber side of the closure during an entire substrate processing cycle or sequence.

21. The method of claim 20, comprising:

purging the closure (191) at the area of the reactive chemical inlet (901, 901') continuously by said reactive chemical during the entire substrate processing cycle or sequence; and

5 purging the closure (191) around that area continuously by carrier gas.

22. A computer program product (1453) comprising program code executable by at least one processor (1451) in a control system (1450) of a substrate processing apparatus, the program code, when executed by the at least one processor (1451), causing the substrate processing apparatus to perform the method of any preceding claim 20-21.

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23. A pulsing valve (100, 300, 900, 900', 900'', 900*), comprising:

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a reactive chemical inlet (101, 901, 901', 901'') to receive reactive chemical;

a reaction chamber outlet (104, 904, 904'') to fluidly connect the pulsing valve to a reaction chamber (530, 1430);

a closure (111, 191, 991) to control fluid flow from the reactive chemical inlet (101, 901, 901', 901'') in the pulsing valve to the reaction chamber outlet (104, 904, 904''); and

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an additional flow channel inlet or outlet (103, 303, 903, 903', 903'')) at the reaction chamber side of the closure to continuously purge the closure (111, 191) through the additional flow channel during an entire substrate processing cycle or sequence.