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(54) **METHOD AND APPARATUS FOR TREATING A GAS STREAM**

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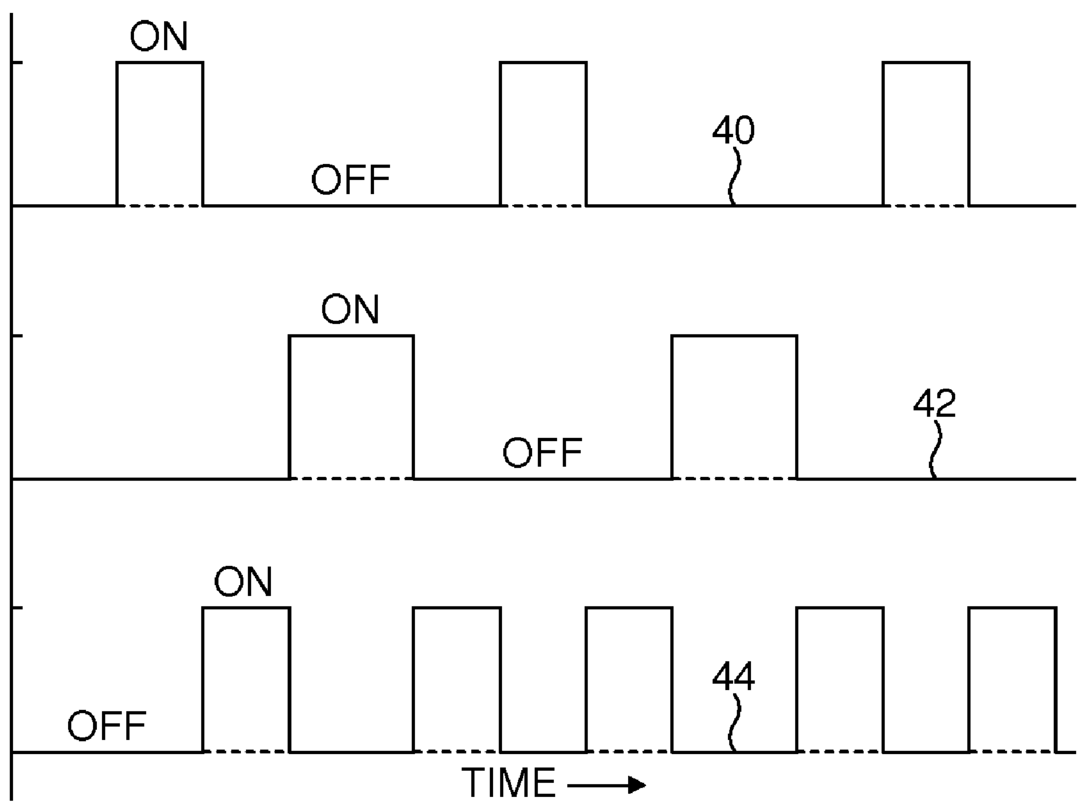
(57) **ABSTRACT**

Apparatus is described for treating a gas stream. The apparatus comprises a gas passage (**72**) for receiving the gas stream, a plurality of hollow cathodes (**94**) located about the gas passage (**72**), means for supplying to the hollow cathodes (**94**) a gaseous source of reactive species for reacting with a component of the gas stream, means for applying a potential to the hollow cathodes (**94**) to form the reactive species from said source, and a reaction chamber (**110**) for receiving the gas stream and the reactive species.



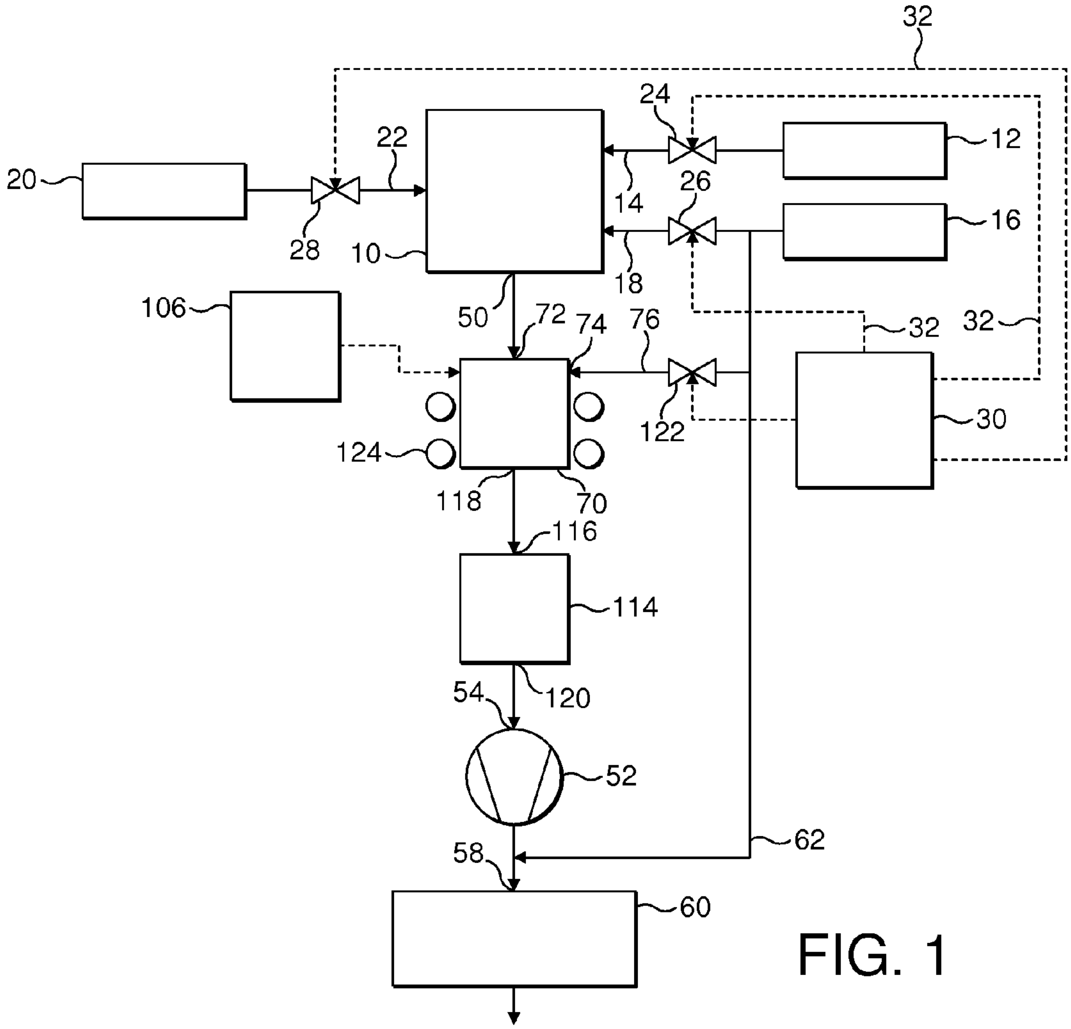

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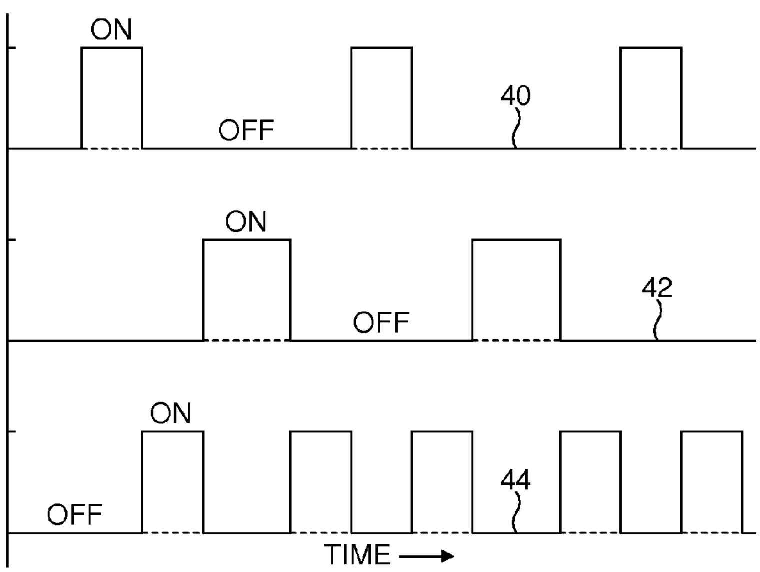
FIG. 1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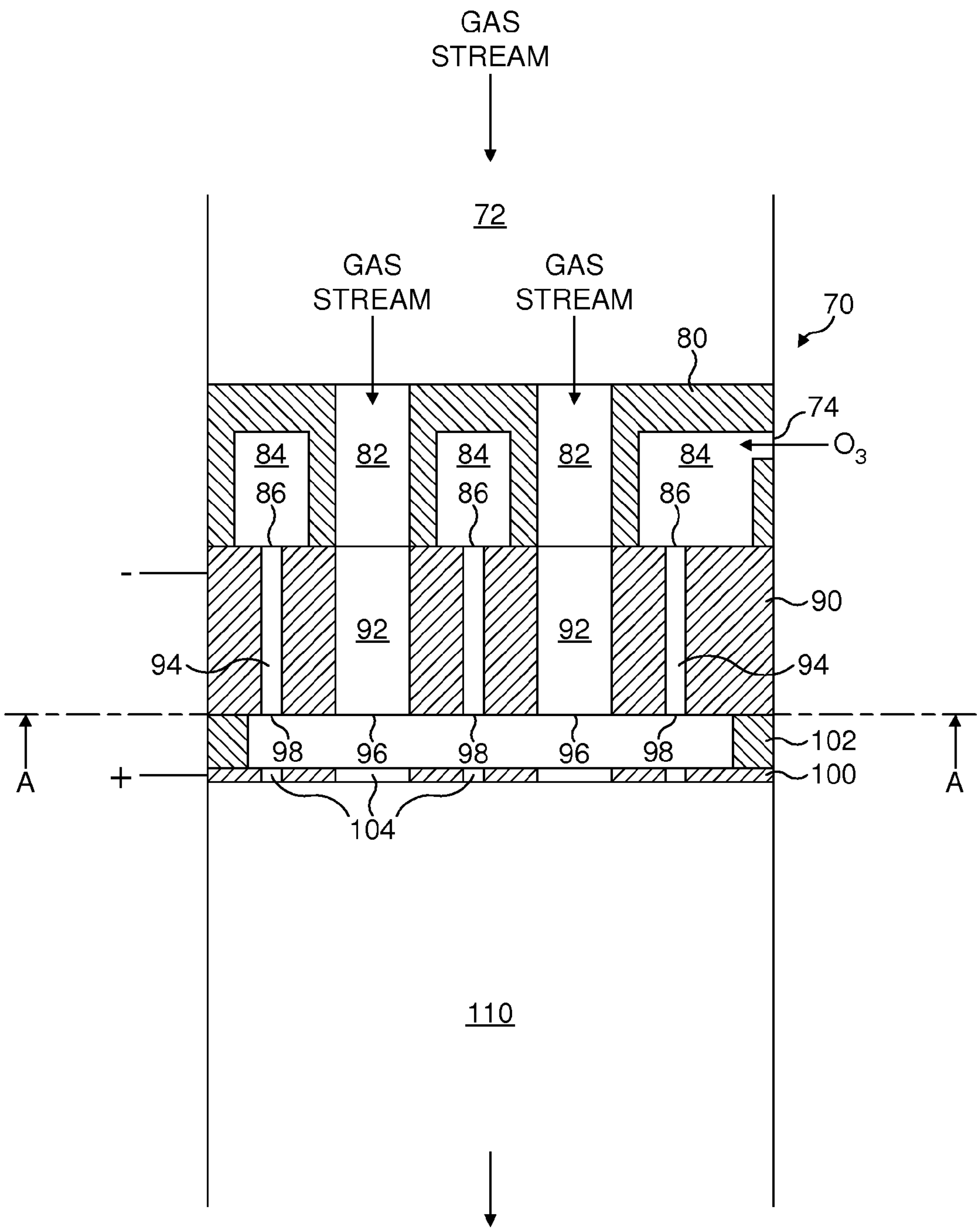
TIME

FIG. 2


GAS
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72
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STREAM
70
80
74
O_3
84
82
84
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86
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92
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94
94
A
102
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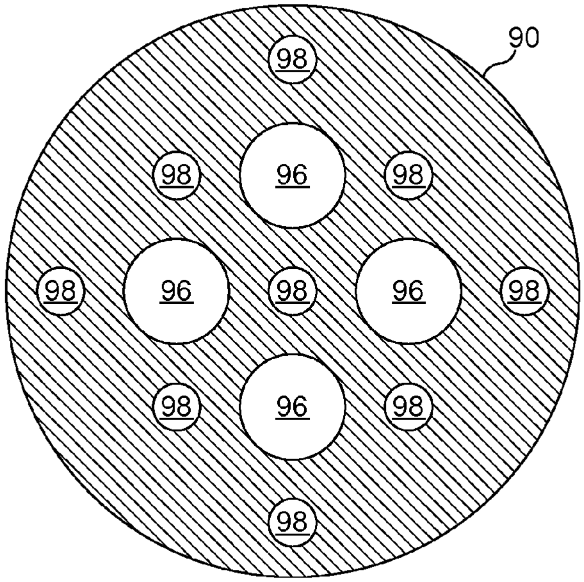
104
110

FIG. 3



90
98
96
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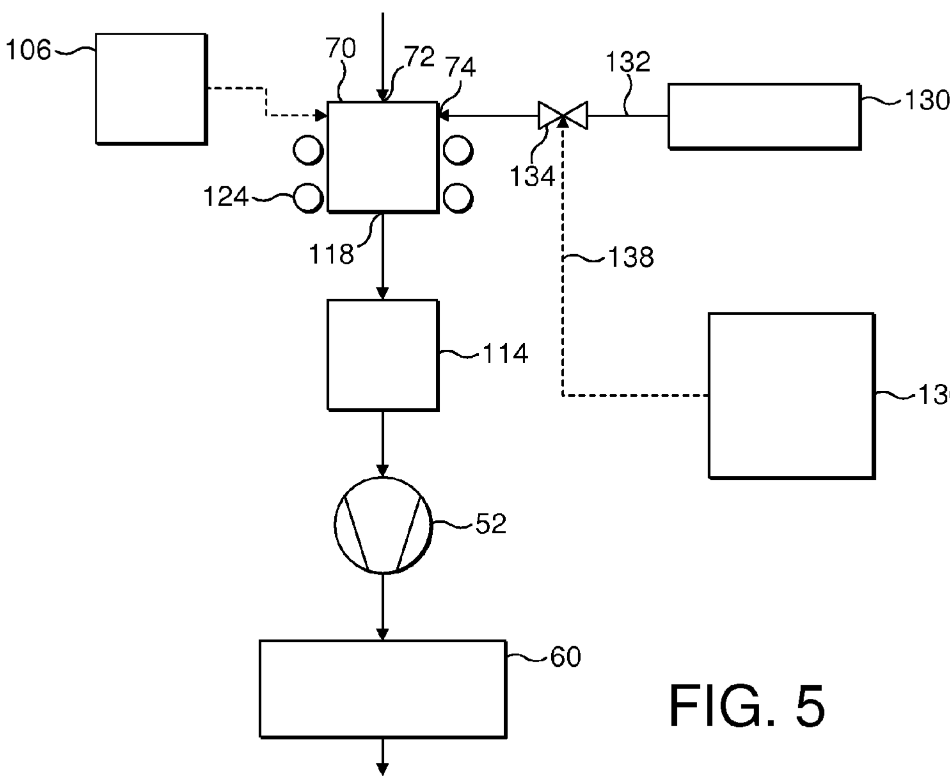
FIG. 4



106
70
72
74
132
130
134
124
118
138
114
136
52
60

FIG. 5

METHOD AND APPARATUS FOR TREATING A GAS STREAM

[0001] The present invention relates to a method of, and apparatus for, treating a gas stream. The invention may be used in the treatment of a gas stream exhausted from a process chamber to which gas is supplied by a pulsed gas delivery system, or in the treatment of a gas stream exhausted from any other process chamber.

[0002] Pulsed gas delivery systems are commonly used in the formation of multi-layer thin films on a batch of substrates located in a process chamber. One such technique for forming thin films on substrates is atomic layer deposition (ALD), in which gaseous reactants, or "precursors", are sequentially delivered to a process chamber to form very thin layers, usually on an atomic-layer scale, of materials on the substrates.

[0003] By way of example, a high dielectric constant capacitor may be formed on a silicon wafer using an ALD technique. Dielectric layers that may be deposited using an ALD technique may include hafnium oxide (HfO_2), aluminium oxide (Al_2O_3), titanium dioxide (TiO_2), zirconium oxide (ZrO_2) or any mixture thereof. Precursors for the formation of such dielectric thin films have the general formula AlR_3, where R is an organic radical, $M(NR_2)_4$, where M is one of Ti, Zr and Hf, and $M(NR'R)_4$, where R and R' are different organic radicals.

[0004] In overview, the first precursor delivered to the process chamber is adsorbed on to the surfaces of the substrates within the process chamber. The non-adsorbed first precursor is drawn from the process chamber by a vacuum pumping system, and the second precursor is then delivered to the process chamber for reaction with the first precursor to form a layer of deposited material. In the deposition chamber, the conditions immediate to the substrates are optimised to minimise gas-phase reactions and maximise surface reactions for the formation of a continuous film on each substrate. Any non-reacted second precursor and any by-products from the reaction between the precursors is then removed from the process chamber by the pumping system. Depending on the structure being formed within the process chamber, the first precursor, or a third precursor, is then delivered to the process chamber.

[0005] A purge step is typically carried out between the delivery of each precursor, for example by delivering a purge gas, such as N_2 or Ar, to the chamber between the delivery of each precursor. The purpose of the purge gas delivery is to remove any residual precursor from the process chamber so as to prevent unwanted reaction with the next precursor supplied to the chamber.

[0006] In practice, only around 5% or less of the precursors supplied to the process chamber are consumed during the deposition process, and so the gas drawn from the chamber during the process chamber will, between supplies of purge gas to the chamber, alternately be rich in the first precursor, and then rich in the second precursor.

[0007] In convention vacuum pumping systems, the gases drawn from the process chamber enter a common foreline leading to a vacuum pump. In the event that the non-reacted precursors meet within the vacuum pumping system, cross-reaction of the precursors can occur, and this can result in both the deposition of solid material and the accumulation of powders within the foreline and the vacuum pump. Particulates and powders that have accumulated within the pump can effectively fill the vacant running clearance between the rotor and stator elements of the pump, leading to a loss of pumping performance and ultimately pump failure. Periodic pump cleaning or replacement is then required to maintain pumping performance, resulting in costly process downtime and increasing manufacturing costs.

[0008] It is an aim of at least the preferred embodiment of the present invention to seek to solve this problem.

[0009] In a first aspect, the present invention provides a method of treating a gas stream exhausted from a process chamber to which a first gaseous precursor and a second gaseous precursor are alternately supplied, the method comprising the steps, upstream from a vacuum pump used to draw the gas stream from the chamber, of conveying the gas stream through a gas passage surrounded by a plurality of hollow cathodes, conveying through the hollow cathodes a source of reactive species for reacting with one of the first and second gaseous precursors, applying a potential to the hollow cathodes to form the reactive species from said source, and, downstream from the gas passage, mixing the reactive species with the gas stream.

[0010] Through the application of a (negative) potential to the hollow cathodes, the source of reactive species can be dissociated into reactive species, such ions, radicals and electrons, in a plasma. By deliberately reacting, say, unconsumed first gaseous precursor with the reactive species emitted from the hollow cathodes before it reaches the pump, reaction within the pump of the unconsumed first gaseous precursor with unconsumed second gaseous precursor subsequently drawn from the chamber by the pump can be inhibited. Conveying the source of reactive species through the hollow cathodes in isolation from the gas to be treated can inhibit the deposition of by-products from the reaction between the reactive species and the gas to be treated within the hollow cathodes.

[0011] The source of the reactive species is preferably a gas that is relatively cheap, safe and readily available. In order to minimise the number of gas supplies the source of reactive species may be the second gaseous precursor, which is supplied from a second precursor supply both to the process chamber and to the hollow cathodes to form reactive species for reaction with the first gaseous precursor. In this case, the source of reactive species may be either an oxidising agent or a reducing agent used in the process conducted within the process chamber. In the preferred embodiments, the source of reactive species is an oxidising agent, and so the second gaseous species may be ozone, and the first gaseous precursor may be an organometallic precursor, which may comprise one of hafnium and aluminium. Examples include tetrakis (ethylmethylamino)hafnium (TEMAH) and trimethyl aluminium (TMA).

[0012] As an alternative to using the second gaseous precursor as the oxidant, an oxidant such as O_2 may be supplied to the hollow cathodes from a separate source to form oxygen radicals and ions for reaction with the first gaseous precursor.

[0013] As this method is suitable for use in treating a gas stream other than that exhausted from a process chamber to which a first gaseous precursor and a second gaseous precursor are alternately supplied, in a second aspect the present invention provides a method of treating a gas stream, the method comprising the steps of conveying the gas stream through a gas passage surrounded by a plurality of hollow cathodes, conveying through the hollow cathodes a gaseous source of reactive species for reacting with a component of the gas stream, applying a potential to the hollow cathodes to form the reactive species from said source, and, downstream from the gas passage, mixing the reactive species with the gas stream.

[0014] In either of the above aspects, each hollow cathode preferably comprises a hollow cylindrical tube. The cylindrical tubes are preferably substantially parallel to the gas passage. The cylindrical tubes preferably comprise a plurality of bores formed in an electrically conductive body at least partially housing the gas passage. The outlets from the hollow cathodes are preferably substantially co-planar with the outlet from the gas passage. A plurality of the gas passages may be provided, and arranged such that the gas stream passes through the gas passages in parallel, each gas passage being surrounded by a plurality of hollow cathodes.

[0015] The gas passage preferably passes through a plenum chamber having an inlet for receiving the source of reactive species, and a plurality of outlets from which the source of reactive species is supplied to the hollow cathodes. The plenum chamber is preferably formed from electrically insulating material. An anode is preferably located downstream from the gas passage and the hollow cathodes, the anode having apertures aligned with the gas passage and the hollow cathodes to permit the gas stream and the reactive species to pass through the anode. The reactive species may subsequently mix with the gas stream within a reactor chamber located downstream from the gas passage. The reactor chamber may be either heated or thermally insulated to promote reaction between the reactive species and the component of the gas stream.

[0016] In the event that the reaction results in the formation of solid material, a separator may be provided between the gas passage and the vacuum pump for separating from the gas stream solid material, such as dust and/or particulates, produced from the reaction. The separator may be provided by any trap device for removing solid material from a gas stream. One example is a dead-leg type of trap device. In the preferred embodiment, the separator is provided by a cyclone separator. An advantage associated with the use of a cyclone separator to separate the solid material from the gas stream is that the solid material will settle out in the bottom of the cyclone separator without increasing the impedance of the separator to the flow of the gas stream. Two or more cyclone separators may be provided in parallel to increase gas conductance.

[0017] In a third aspect the present invention provides apparatus for treating a gas stream, the apparatus comprising a gas passage for receiving the gas stream, a plurality of hollow cathodes located about the gas passage, means for supplying to the hollow cathodes a gaseous source of reactive species for reacting with a component of the gas stream, means for applying a potential to the hollow cathodes to form the reactive species from said source, and a reaction chamber for receiving the gas stream and the reactive species.

[0018] In a fourth aspect the present invention provides apparatus for treating a gas stream exhausted from a process chamber to which a first gaseous precursor and a second gaseous precursor are alternately supplied, the apparatus comprising a gas passage for receiving the gas stream, a plurality of hollow cathodes located about the gas passage, means for supplying to the hollow cathodes a gaseous source of reactive species for reacting with one of the first and second gaseous precursors, means for applying a potential to the hollow cathodes to form the reactive species from said source, and a reaction chamber for receiving the gas stream and the reactive species.

[0019] In a fifth aspect the present invention provides an atomic layer deposition apparatus comprising a process chamber, a first gaseous precursor supply for supplying a first gaseous precursor to the chamber, a second gaseous precursor supply for supplying a second gaseous precursor to the chamber, a vacuum pump for drawing a gas stream from the process chamber, and, between the process chamber and the vacuum pump, a plurality of gas passages for receiving the gas stream from the process chamber, and a plurality of hollow cathodes located about the gas passages for receiving second gaseous precursor from the second precursor gas supply, the apparatus comprising means for applying a potential to the hollow cathodes to form from the second gaseous precursor reactive species for reacting with first gaseous precursor within the gas stream to form solid material, a reaction chamber for receiving the gas stream and the reactive species, and a separator for receiving a gas stream exhausted from the reaction chamber and separating solid material from that gas stream.

[0020] Features described above in relation to method aspects of the invention are equally applicable to apparatus aspects, and vice versa.

[0021] Preferred features of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

[0022] FIG. **1** illustrates schematically an atomic layer deposition apparatus including apparatus for treating the gas stream exhaust from the process chamber;

[0023] FIG. **2** illustrates the sequence of supply of gases to the process chamber of the apparatus of FIG. **1**;

[0024] FIG. **3** illustrates in more detail the apparatus for treating the gas stream;

[0025] FIG. **4** is a cross-sectional view of the apparatus of FIG. **3**; and

[0026] FIG. **5** illustrates apparatus for treating a gas stream separate from any process apparatus.

[0027] With reference first to FIG. **1**, an atomic layer deposition (ALD) apparatus comprises a process chamber **10** for receiving a batch of substrates to be processed simultaneously within the process chamber **10**. The process chamber **10** receives separately and alternately two or more different gaseous reactants or precursors for use in forming layers of material on the exposed surfaces of the substrates. In the example illustrated in FIG. **1**, a first precursor supply **12** is connected to the process chamber **10** by a first precursor supply line **14** for supplying a first precursor to the process chamber **10**, and a second precursor supply **16** is connected to the process chamber **10** by a second precursor supply line **18** for supplying a second precursor to the process chamber **10**. A purge gas supply **20** is also connected to the process chamber **10** by a purge gas supply line **22** for supplying a purge gas such as nitrogen or argon to the process chamber **10** between the supply of the precursors to the process chamber **10**.

[0028] The supply of the precursors and the purge gas to the process chamber **10** is controlled by the opening and closing of gas supply valves **24**, **26**, **28** located in the supply lines **14**, **18**, **22** respectively. The operation of the gas supply valves is controlled by a supply valve controller **30** which issues control signals **32** to the gas supply valves to open and close the valves according to a predetermined gas delivery sequence. A typical gas delivery sequence involving two gaseous precursors and a purge gas is illustrated in FIG. **2**. The first trace **40** represents the stepped delivery sequence for the first gaseous precursor, and the second trace **42** represents the stepped delivery sequence for the second gaseous precursor. As described above, the first and second precursors are alternately supplied to the chamber to form layers of solid material on the batches of substrates located within the process chamber **10**. The duration of each pulsed delivery of precursor to the process chamber **10** is defined for the particular process to be performed within the process chamber **10**; in this example, the duration of each pulsed delivery of the second precursor to the process chamber **10** is longer than that for the first precursor. The third trace **44** represents the stepped delivery sequence for the purge gas that is introduced into the process chamber **10** between the delivery of first and second gaseous precursors to flush the process chamber **10** before introducing the next gaseous precursor.

[0029] Returning to FIG. **1**, a vacuum pumping system is connected to the outlet **50** of the process chamber **10** for drawing a gas stream from the process chamber **10**. The pumping system comprises a vacuum pump **52** for receiving the gas stream through an inlet **54** thereof and exhausting the gas stream at an elevated pressure through an exhaust **56** thereof. The gas stream exhausted from the vacuum pump **52** is conveyed to an inlet **58** of an abatement device **60**, for example a thermal processing unit or a wet scrubber, for removing one or more species from the gas stream before it is exhausted to the atmosphere.

[0030] In one example, the first gaseous precursor is an organometallic precursor containing one of hafnium and aluminium, such as tetrakis(ethylmethylamino) hafnium (TEMAH) or trimethyl aluminium (TMA), and the second gaseous precursor is an oxidant, such as ozone. The second precursor supply **16** may therefore be provided by an ozone generator. Currently available ozone generators can be difficult to start and stop in synchronisation with the pulsed delivery sequence of ozone to the process chamber **10**. In view of this, the ozone generator **16** may be continuously generating ozone during the ALD process, and when ozone is not being delivered to the process chamber **10** the ozone may be diverted along ozone supply line **62** to a location downstream from the vacuum pump **52**, for example to the inlet of a backing pump (not illustrated) provided between the vacuum pump **52** and the abatement device **60**, or directly to a second inlet of the abatement device **60**, where the ozone may assist in the abatement of the gas stream exhausted from the vacuum pump **52**.

[0031] In view of the alternating supply of first and second gaseous precursors to the process chamber **10**, the gas stream drawn from the process chamber **10** will alternate between a first precursor-rich gas stream, comprising unconsumed first precursor and by-products from the reaction between the precursors, and a second precursor-rich gas stream, comprising unconsumed second precursor and the by-products, with a purge gas-rich gas stream being drawn from the process chamber **10** between these precursor-rich gases. Each of the precursor-rich gas streams is also likely to contain traces of purge gas and other contaminants.

[0032] In order to inhibit mixing of the unconsumed precursors within the vacuum pump **52**, which could lead to undesirable reaction between the precursors and the formation of dust and/or powders within the vacuum pump, apparatus **70** is provided between the outlet **50** of the process chamber **10** and the inlet **54** of the vacuum pump **52** to treat the gas stream exhausted from the process chamber **10** so as to reduce the amount of one of the first and second precursors that enters the vacuum pump **52**. In the example illustrated in FIG. **1**, the amount of the first precursor entering the vacuum pump **52** is reduced.

[0033] The apparatus **70** for treating the gas stream exhausted from the process chamber **10** has a first inlet **72** for receiving the gas stream exhausted from the process chamber **10**, and a second inlet **74** for receiving a source of reactive species for reacting with the chosen precursor to be at least partially removed from the gas stream. In the illustrated example, a supply for supplying the source of reactive species to the apparatus **70** is conveniently provided by the ozone generator **16**. A reactant supply line **76** is connected between the ozone supply line **62** and the second inlet **74** of the gas mixing chamber **70** to supply ozone to the apparatus **70**.

[0034] Part of the apparatus **70** is illustrated in more detail in FIG. **3**. The apparatus **70** comprises an electrically insulating body **80** having a plurality of parallel, cylindrical bores **82** extending therethrough for receiving the gas stream from the first inlet **72**. The body **80** also defines a plenum chamber **84** located about the bores **82**, and which receives the source of reactive species from the second inlet **74**. The plenum chamber **84** has a plurality of cylindrical outlets **86** surrounding the bores **82** through which the source of reactive species is exhausted from the plenum chamber **84**.

[0035] The apparatus **70** also comprises a cathode **90** located downstream from the electrically insulating body **80**. The cathode **90** is provided by an electrically conducting body having a first set of parallel, cylindrical bores **92** extending therethrough for receiving the gas stream from the channels **82**. The bores **92** in the cathode **90** have substantially the same diameter as the bores **82** in the body **80**. The bores **82** of the body **80** and the bores **92** of the cathode **90** together define gas passages arranged such that the gas stream passes through the gas passages in parallel.

[0036] The cathode **90** also has a second set of bores **94** extending therethrough for receiving the gas stream from the outlets **86** of the body **80**. The diameter of the bores **94** is smaller than the diameter of the bores **92**. The bores **94** are axially aligned with the outlets **86** from the plenum chamber **84**, and are arranged substantially parallel to the bores **92**. The outlets **96** from the bores **92** are substantially co-planar with the outlets **98** from the bores **94**. With reference to FIG. **4**, each of the bores **92** is surrounded by a plurality of the smaller bores **94**, in this example by four bores but the bores **92** may be surrounded by any number of the smaller bores **94**.

[0037] The apparatus further comprises an anode **100** spaced from the cathode by an electrical insulator **102**. The anode **100** has a plurality of apertures **104** which are aligned with the outlets **96**, **98** of the bores **92**, **94** of the cathode **90**. A power source **106** is provided to charge the cathode **90** to a cathode (negative) potential and the anode **100** to an anode (positive) potential.

[0038] The application of the negative potential to the cathode **90** causes the bores **94** to act as hollow cathodes, which results in the dissociation of the source of reactive species, in this example ozone, into reactive species, in this example electrons, oxygen ions and oxygen radicals, in a plasma. The reactive species and the gas stream pass through the apertures **104** in the anode **100** and enter a reaction chamber **110** within which the reactive species react with unconsumed first gaseous precursor in the gas stream.

[0039] The source of reactive species is preferably chosen so that the reaction that takes place within the reaction chamber **110** replicates the reaction that would occur between unconsumed first and second gaseous precursors within the vacuum pump **52**. Therefore, a product from the reaction between the reactive species and the first gaseous precursor is the solid material, such as a dust and/or powder, that would otherwise be formed in the vacuum pump **52** through the reaction between the unconsumed precursors. Consequently, the a separator **114** may be provided for removing this solid material from the gas stream exhausted from the reaction chamber **110** before it enters the vacuum pump **52**. With reference to FIG. **1**, the separator **114** has an inlet **116** connected to an outlet **118** of the apparatus **70**. The separator **114** is preferably a cyclone separator, which receives the solid material-laden gas stream from the apparatus **70**, and, in a manner known in the art, separates the solid material from the gas stream, retaining the solid material therewithin and exhausting the gas stream from an outlet **120** thereof to the inlet **54** of the vacuum pump **52**.

[0040] The supply of the source of reactive species to the apparatus **70** is controlled by the opening and closing of reactant supply valve **122** located in the reactant supply line **76**. The operation of the reactant supply valve **122** is controlled by the supply valve controller **30**, which issues control signals **32** to the reactant supply valve **76** to open and close in synchronisation with the delivery of the first gaseous precursor to the process chamber **10**, so that the source of reactive species is supplied to the apparatus **70** with a stepped delivery sequence that is similar to that for the first gaseous precursor. The amount of source of reactive species periodically delivered to the apparatus **70** is preferably at least sufficient to react with the amount of the first gaseous precursor that is supplied to the process chamber **10**.

[0041] In order to increase the reaction rate between the reactive species and the first gaseous precursor within the reaction chamber **110**, a heater **124** may optionally extend about the reaction chamber **110** for heating the reaction chamber **110**. Alternatively, the reaction chamber **110** may be thermally insulated.

[0042] In the example illustrated in FIG. **1**, the apparatus **70** is separate from the separator **114**. However, the apparatus **70** may be mounted on, or integral with, the separator **114**. Two or more separators **114** may be provided in parallel to enable one separator to be serviced while the other is operational.

[0043] The apparatus **70** has been described above as part of an ALD apparatus **10**. However, the apparatus **70** may be used to treat gas streams other than those exhausted from an ALD process chamber. For example, the apparatus **70** may be used to treat gases exhausted from a CVD or other deposition chamber, or any other gas stream containing a component, for example NH_3, which may be detrimental to the vacuum pump **52**. FIG. **5** illustrates an example in which the apparatus is used to treat any gas stream. In view of the absence of the source of the second precursor gas for supplying the source of reactive species to the second inlet **74** of the apparatus **70**, a separate source **130** of reactive species, in this example an oxidant such as oxygen, is connected to the second inlet **74** by a reactant supply line **132**. The supply of oxygen to the apparatus **70** is controlled by opening and closing valve **134**. As illustrated in FIG. **5**, a controller **136** may be provided by issuing signals **138** to the valve **134** to control the supply of oxygen to the apparatus **70**. Depending on the nature of the reaction between the reactive species and the component of the gas stream, a separator **114** may again be provided downstream from, or integral with, the apparatus **70**. This separator **114** may be provided by a cyclone trap for removing particulates from the gas stream, a cold trap for removing condensable species from the gas stream, or a hot trap.

1. A method of treating a gas stream, the method comprising the steps of:

conveying the gas stream through a gas passage surrounded by a plurality of hollow cathodes;

conveying through the plurality of hollow cathodes a gaseous source of reactive species for reacting with a component of the gas stream exhausted from the gas passage;

applying a potential to the hollow cathodes to form the reactive species from said source; and

mixing the reactive species with the gas stream downstream from the gas passage.

2. The method according to claim **1** wherein each hollow cathode comprises a hollow cylindrical tube.

3. The method according to claim **2** wherein the cylindrical tubes are substantially parallel to the gas passage.

4. The method according to claim **2** wherein the cylindrical tubes comprise a plurality of bores formed in an electrically conductive body at least partially housing the gas passage.

5. The method according to claim **1** comprising the step of positioning an anode downstream from the gas passage and the hollow cathode, the anode having apertures aligned with the gas passage and the hollow cathodes.

6. The method according to claim **1** wherein the outlets from the hollow cathodes are substantially co-planar with the outlet from the gas passage.

7. The method according to claim **1** comprising the step of arranging a plurality of said gas passages such that the gas stream passes through the gas passages in parallel, each gas passage being surrounded by a plurality of hollow cathodes.

8. The method according to claim **1** comprising the step of mixing the reactive species with the gas stream within a reactor chamber located downstream from the gas passage.

9. The method according to claim **8** comprising the step of heating the reactor chamber to promote reaction between the reactive species and the component of the gas stream.

10. The method according to claim **8** comprising the step of thermally insulating the reactor chamber to promote reaction between the reactive species and the component of the gas stream.

11. The method according to claim **1** comprising the step of conveying the gas stream to a separator to separate solid material from the gas stream.

12. The method according to claim **11** wherein the separator is a cyclone separator.

13. The method according to claim **1** wherein the source of the reactive species is an oxidant.

14. The method according to claim **13** wherein the source of the reactive species is oxygen or ozone.

15. A method according to claim **1** wherein said component of the gas stream is one of a first gaseous precursor and a second gaseous precursor alternately supplied to the process chamber

16. A method of treating a gas stream exhausted from a process chamber to which a first gaseous precursor and a second gaseous precursor are alternately supplied, the method comprising the steps of:

upstream from a vacuum pump used to draw the gas stream from the chamber, conveying the gas stream through a gas passage surrounded by a plurality of hollow cathodes;

conveying through the hollow cathodes a source of reactive species for reacting with one of the first and second gaseous precursors;

applying a potential to the hollow cathodes to form the reactive species from said source; and

downstream from the gas passage, mixing the reactive species with the gas stream.

17. The method according to claim **15** wherein said one of the first and second gaseous precursors is the first gaseous precursor, and the source of reactive species is the second gaseous precursor.

18. The method according to claim **17** wherein said one of the first and second gaseous precursors is an organometallic precursor.

19. The method according to claim **18** wherein the organometallic precursor comprises one of hafnium and aluminium.

20. Apparatus for treating a gas stream, the apparatus comprising:

a gas passage for receiving the gas stream;

a plurality of hollow cathodes located about the gas passage;

means for supplying to the hollow cathodes a gaseous source of reactive species for reacting with a component of the gas stream;

means for applying a potential to the hollow cathodes to form the reactive species from said source; and

a reaction chamber for receiving the gas stream and the reactive species.

21. Apparatus according to claim **20** wherein each hollow cathode comprises a hollow cylindrical tube.

22. Apparatus according to claim **21** wherein the cylindrical tubes are substantially parallel to the gas passage.

23. Apparatus according to claim **21** wherein the cylindrical tubes comprise a plurality of bores formed in an electrically conductive body at least partially housing the gas passage.

24. Apparatus according to claim **23** wherein the supply means comprises a plenum chamber having an inlet for receiving the source of reactive species, and a plurality of outlets from which the source of reactive species is supplied to the hollow cathodes.

25. Apparatus according to claim **20** comprising an anode located downstream from the gas passage and the hollow cathode, the anode having apertures aligned with the gas passage and the hollow cathodes.

26. Apparatus according to claim **25** wherein the anode is located in the reaction chamber.

27. Apparatus according to claim **20** wherein the outlets from the hollow cathodes are substantially co-planar with the outlet from the gas passage.

28. Apparatus according to claim **20** comprising a plurality of said gas passages arranged such that the gas stream passes through the gas passages in parallel, each gas passage being surrounded by a plurality of hollow cathodes.

29. Apparatus according to claim **20** comprising a heater for heating the reaction chamber to promote reaction between the reactive species and the component of the gas stream.

30. Apparatus according to claim **20** wherein the reactor chamber is thermally insulated to promote reaction between the reactive species and the component of the gas stream.

31. Apparatus according to claim **20** comprising a separator for receiving a gas stream exhausted from the reaction chamber and separating solid material from that gas stream.

32. Apparatus according to claim **31** wherein the separator is a cyclone separator.

33. Apparatus for treating a gas stream exhausted from a process chamber to which a first gaseous precursor and a second gaseous precursor are alternately supplied, the apparatus comprising a gas passage for receiving the gas stream, a plurality of hollow cathodes located about the gas passage, means for supplying to the hollow cathodes a gaseous source of reactive species for reacting with one of the first and second gaseous precursors, means for applying a potential to the hollow cathodes to form the reactive species from said source, and a reaction chamber for receiving the gas stream and the reactive species.

34. Apparatus according to claim **33** wherein said one of the first and second gaseous precursors is the first gaseous precursor, and the source of reactive species is the second gaseous precursor.

35. An atomic layer deposition apparatus comprising a process chamber, a first gaseous precursor supply for supplying a first gaseous precursor to the chamber, a second gaseous precursor supply for supplying a second gaseous precursor to the chamber, a vacuum pump for drawing a gas stream from the process chamber, and, between the process chamber and the vacuum pump, a plurality of gas passages for receiving the gas stream from the process chamber, and a plurality of hollow cathodes located about the gas passages for receiving second gaseous precursor from the second precursor gas supply, the apparatus comprising means for applying a potential to the hollow cathodes to form from the second gaseous precursor reactive species for reacting with first gaseous precursor within the gas stream to form solid material, a reaction chamber for receiving the gas stream and the reactive species, and a separator for receiving a gas stream exhausted from the reaction chamber and separating solid material from that gas stream.

36. Apparatus according to claim **33** wherein the first gaseous precursor is an organometallic precursor.

37. Apparatus according to claim **36** wherein the organometallic precursor comprises one of hafnium and aluminium.

38. Apparatus according to claim **33** wherein the second gaseous precursor is an oxidant.

39. Apparatus according to claim **38** wherein the second gaseous precursor is ozone.

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