

PLASMA-ENHANCED ATOMIC LAYER DEPOSITION APPARATUS**FIELD OF THE INVENTION**

The present invention relates to a plasma-enhanced atomic layer deposition apparatus for processing a surface of a substrate and more particularly to a plasma-enhanced atomic layer deposition apparatus as defined in the preamble of the independent claim.

BACKGROUND OF THE INVENTION

In typical prior art plasma-enhanced atomic layer deposition apparatuses, the electrode is connected to a top part of a reaction chamber and a bottom part of the reaction chamber is grounded.

One of the problems associated with the prior art is that film modification and film crystallization or other post treatments in plasma enhanced atomic layer deposition apparatuses such as plasma-in-situ or post treatment are not possible because of the limitations of the apparatuses.

BRIEF DESCRIPTION OF THE INVENTION

An object of the present invention is to provide a more effective plasma-enhanced atomic layer deposition apparatus in which the application of the apparatus can be expanded for example to film modification or film crystallization.

The objects of the invention are achieved by a plasma-enhanced atomic layer deposition apparatus which is characterized by what is stated in the independent claim. The preferred embodiments of the invention are disclosed in the dependent claims.

The invention is based on the idea of providing two separate power sources such that one power source is electrically connected to a showerhead nozzle and the other power source is electrically connected to a substrate holder such that the plasma discharge between the electrodes is a more efficient so that the deposition on the surface of the substrate can be even more precise.

A plasma-enhanced atomic layer deposition apparatus according to the invention for processing a surface of a substrate successively with at least a first precursor gas and a second precursor gas according to principles of atomic layer deposition comprising a vacuum chamber having a top wall, a bottom wall and at least one side wall, said walls of the vacuum chamber forming a vacuum space inside the vacuum chamber, a reaction chamber arranged inside the vacuum chamber, the reaction chamber having a top wall, a bottom wall and at least one

side wall, said walls of the reaction chamber forming a reaction space inside the reaction chamber, a substrate holder for supporting a substrate during the atomic layer deposition, and a showerhead nozzle arranged opposite the substrate holder such that a reaction zone is formed between the showerhead nozzle and the substrate holder in the reaction space. The showerhead nozzle comprising precursor supply openings through which precursor gases are supplied to the reaction zone. The apparatus further comprising a first power source electrically connected to the substrate holder, and a second power source electrically connected to the showerhead nozzle. Said first power source and second power source are arranged outside the vacuum chamber.

In other words, the apparatus comprises two separate power sources electrically connected to the reaction chamber in such a way that one is connected to the showerhead nozzle and the other to the substrate holder, which are spaced apart from each other in the reaction chamber, and both power sources are arranged outside the vacuum chamber.

According to the invention, the first power source is an RF power source and the second power source is an RF power source, or alternatively the first power source is a DC power source and the second power source is an RF power source.

In other words, the showerhead nozzle is electrically connected to the RF (radio frequency) power source, but the substrate holder may be electrically connected to the RF power source or alternatively to a DC (direct current) power source.

According to the invention the apparatus further comprises a first electrode and a second electrode, which are independently controlled separate electrodes.

In other words, the first power source is electrically connected to the first electrode and the second power source is electrically connected to the second electrode. The power source are separate and therefore the two electrodes that are separate electrodes are also separately controlled.

According to the invention, the first power source arranged outside the vacuum chamber is electrically connected to the substrate holder via the first electrode, wherein said first electrode is arranged to extend through the wall of the vacuum chamber to the substrate holder via the vacuum space of the vacuum chamber and through the wall of the reaction chamber.

In other words, the first electrode is electrically connected to the first power source which is located outside the vacuum chamber; therefore, the first

electrode extends through the vacuum chamber to the reaction chamber so that the electrical connection to the substrate holder that is arranged inside the reaction chamber is possible. The first electrode extending through the vacuum chamber and through the wall of the reaction chamber is insulated so that there is no electrical connection between the structures of the vacuum chamber and the first electrode nor is there any electrical connection between the structures of the reaction chamber.

According to the invention, the first electrode comprises a first plate electrode having an electrical connection with the substrate holder and extends parallel to a support surface of the substrate holder at which the substrate is placed during deposition.

In other words, the first electrode which extends through the vacuum chamber and to the reaction chamber and has the electrical connection with the substrate holder, comprises the first plate electrode which forms the electrical connection with the substrate holder. The first plate electrode comprises a plane having the electrical connection with the substrate holder.

According to the invention, the first plate electrode is arranged inside the reaction chamber.

In other words, the first electrode extending through the vacuum chamber and to the reaction chamber is arranged to extend inside the reaction chamber such that the first plate electrode of the first electrode is arranged in the reaction space of the reaction chamber.

According to the invention, the first electrode further comprises a rod electrode which extends through the vacuum space of the vacuum chamber and through the wall of the reaction chamber and is connected to the plate electrode.

In other words, the first electrode extending through the vacuum chamber to the reaction chamber is a rod electrode.

According to the invention, the substrate holder is at least partly formed of the first electrode.

In other words, the first plate electrode forming part of the first electrode can be embedded to the substrate holder, or form at least part of a surface of the substrate holder, or the plate electrode can form the substrate holder on which the substrate is placed during the deposition.

According to the invention, the second power source arranged outside the vacuum chamber is electrically connected to the showerhead nozzle via the second electrode, wherein said second electrode is arranged to extend through the

wall of the vacuum chamber to the showerhead nozzle through the wall of the reaction chamber.

In other words, the second power source which is separate from the first power source is electrically connected to the showerhead nozzle through the second electrode. The second power source is provided outside the vacuum chamber, so the second electrode extends through the vacuum chamber to the structures of the reaction chamber and through the top wall of the reaction chamber to the showerhead nozzle which is preferably provided in connection with the top wall of the reaction chamber or close to the top wall of the reaction chamber. In an embodiment of the apparatus in which the reaction chamber and the vacuum chamber form a connection between the top wall of the vacuum chamber and the top wall of the reaction chamber and there is no vacuum space between said top walls then the second electrode extends from the structures of the vacuum chamber directly to the structures of the reaction chamber without extending through the vacuum space of the vacuum chamber.

According to the invention, the showerhead nozzle comprises the second electrode as an integral part of the showerhead nozzle.

In other words, the second electrode can be part of the showerhead nozzle such that the showerhead nozzle and the second electrode form one unit and the second electrode is integrated into the shower head nozzle.

According to the invention, the first power source connected to the first electrode and the second power source connected to the second electrode are arranged outside the vacuum chamber on the side of the top wall side of the vacuum chamber.

In other words, the first power source and the second power source are arranged on the same side of the vacuum chamber, and preferably on the top wall side of the vacuum chamber. Thereby the electrical connections from the power sources to the first and second electrodes and the passage of the electrodes in the apparatus are arranged through the top wall of the vacuum chamber towards the reaction chamber arranged inside the vacuum chamber.

According to the invention, the first power source connected to the first electrode and the second power source connected to the second electrode are arranged outside the vacuum chamber on the same wall side of the vacuum chamber.

In other words, the first power source and the second power source can be provided on the side wall side of the vacuum chamber, on the top wall side of

the vacuum chamber or on the bottom wall side of the vacuum chamber. Thereby the electrical connections from the power sources to the first and second electrodes and the passage of the electrodes in the apparatus are arranged through the same wall of the vacuum chamber towards the reaction chamber arranged
5 inside the vacuum chamber.

According to the invention, the showerhead nozzle is arranged in connection with the top wall of the reaction chamber and the substrate holder is arranged in connection with the bottom wall of the reaction chamber, the reaction zone formed between the showerhead nozzle and the substrate holder has a height
10 from an output face of the showerhead nozzle to a top surface of the substrate holder, said height is between 10 mm – 40 mm.

In other words, the reaction zone between the showerhead nozzle comprising the electrical connection to the second power source and the substrate holder having the electrical connection to the first power source is relatively small
15 and the showerhead nozzle and the substrate holder are close to each other so that the plasma discharge generated between them is effective and for example film crystallization or film modification can be achieved on the surface of the substrate placed on the substrate holder.

According to the invention, the reaction space is provided with a plasma
20 grid, said plasma grid is arranged in the reaction zone closer to the showerhead nozzle than to the substrate holder.

In other words, the plasma grid can be provided to even the plasma discharge generated in the reaction zone.

According to the invention, the apparatus comprises a first insulation
25 such that the first electrode is electrically separated from structures of the reaction chamber through the first insulation, and a second insulation such that the second electrode is electrically separated from structures of the reaction chamber through the second insulation.

In other words, the first electrode comprises the first insulation so that
30 all the connections between the structures of the vacuum chamber and the reaction chamber and the first electrode are separated by the first insulation. The first rod electrode of the first electrode is preferably surrounded by the first insulation as a sock-like or tubular insulation. The first insulation surrounding the first rod electrode preferably extends along the first rod electrode along its entire length.
35 The first plate electrode is electrically separated from the reaction chamber also through the first insulation, the first insulation may then be arranged as an

insulation layer between the structures of the reaction chamber such as the bottom wall of the reaction chamber and the first plate electrode. The first insulation arranged in connection with the first electrode, and specifically in connection with the first electrode which is in the form of a plate electrode, is preferably larger than the first electrode.

According to the invention, the apparatus further comprises at least one precursor gas source arranged outside the vacuum chamber and in fluid connection with the showerhead nozzle for supplying precursor gases through the supply openings to the reaction zone.

In other words, the precursor gas source is in fluid communication with the showerhead nozzle through a gas conduit extending between the precursor gas source and the showerhead nozzle. When there are more than one precursor gas source all the sources can be in fluid communication with the showerhead nozzle through the same gas conduit or there may be several gas conduits extending between the showerhead nozzle and the respective precursor gas sources. The precursor gas supplied through the showerhead nozzle comprises radical gas so that the radical gas is supplied toward the substrate placed on the substrate holder opposite the showerhead nozzle at the reaction zone distance from the showerhead nozzle.

According to the invention, the apparatus further comprises a separate precursor gas inlet provided in connection with the wall of the reaction chamber for supplying precursor gas to the reaction zone between the showerhead nozzle and the substrate holder.

In other words, the apparatus may comprise in addition to the showerhead nozzle a separate precursor gas inlet in connection with the reaction chamber. The separate precursor gas inlet is preferably arranged at the side wall of the reaction chamber or to the bottom wall of the reaction chamber such that a discharge outlet is provided on the opposite side of the reaction chamber than the separate precursor gas inlet for providing a crossflow through the reaction space and through the reaction zone between the showerhead nozzle and the substrate holder.

According to the invention the apparatus further comprises a discharge outlet provided in connection with the wall of the reaction chamber for discharging precursor gases out from the reaction space, the discharge outlet is connected to a discharge pump outside the vacuum chamber.

An advantage of the invention is that by providing two separate power

sources and two separate electrodes on both sides of the reaction space formed by the showerhead nozzle and the substrate holder, a more efficient plasma is created directly on the substrate and additional energy is produced for the substrate. Another advantage of the invention is that by providing two separate power
5 sources and two separate electrodes on both sides of the reaction space formed by the showerhead nozzle and the substrate holder, the plasma species coming to the substrate can be more accurately selected. The reaction zone is small enough to provide an effective deposition on the surface of the substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

10 The invention is described in detail by means of specific embodiments with reference to the enclosed drawings, in which

Figure 1 shows a plasma-enhanced atomic layer deposition apparatus according to the invention;

15 Figure 2 shows another embodiment of a plasma-enhanced atomic layer deposition apparatus according to the invention; and

Figure 3 shows yet another a plasma-enhanced atomic layer deposition apparatus according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

The apparatus shown in figure 1-3 comprises a vacuum chamber 1
20 having a top wall 11, a bottom wall 12 and side walls 13 defining a vacuum space 10 inside the vacuum chamber 1. The apparatus also comprises a reaction chamber 2 inside the vacuum chamber 1. The reaction chamber 2 comprises a top wall 21, a bottom wall 22 and side walls 23 defining a reaction space 20 inside the reaction chamber 2. The reaction chamber 2 is provided inside the vacuum chamber 1 such
25 that the vacuum space 10 surrounds the reaction chamber 2. The reaction chamber 2 may have a direct contact with the structures of the vacuum chamber 1 for example through the top wall 21 of the reaction chamber 2.

The apparatus comprises a showerhead nozzle 5 provided in the reaction chamber 2 and supplying precursor gas from a precursor gas source G to
30 the reaction space 20 through precursor supply openings 6 provided in the showerhead nozzle 5. Also, plasma gas may be supplied through the precursor supply opening 6 of the showerhead nozzle to the reaction space 20. The apparatus also comprises a substrate holder 4 provided in the reaction chamber 2 and arranged to support a substrate 41 during the ALD deposition. The substrate
35 holder 4 is arranged opposite to the showerhead nozzle 5 at a distance from the

showerhead nozzle 5 such that a reaction zone 20a is formed between the showerhead nozzle 5 and the substrate holder 4. The reaction space 20 may also comprise a plasma grid 8 as shown in figure 1 and 2, the plasma grid 8 extending in the reaction space 20 parallel to the showerhead nozzle 5 and the substrate holder 4. The plasma grid 8 is arranged to extend between opposite side walls 23 of the reaction chamber 2. The plasma grid 8 is used for creating a remote plasma function. The apparatus shown in figure 3 does not comprise the plasma grid 8 because the figure 3 shows an example of a direct plasma, so the plasma grid 8 is not used and it can be removed from the apparatus when the direct plasma is used. Otherwise, the presence or absence of the plasma grid 8 does not affect the rest of the configuration of the apparatus shown in Figures 1-3.

The figures 1-3 also show that the power sources PS1, PS2 which are separately electrically connected to the showerhead nozzle 5 and the substrate holder 4 are arranged outside the vacuum chamber 1 on the same side of the vacuum chamber 1. This provides an efficient way to maintain the power sources PS1, PS2. The first electrode E1 which receives the electrical power from the first power source PS1 is electrically connected to the substrate holder 4. The first electrode E1 comprises a rod electrode E1_R and a plate electrode E1_P which form the first electrode E1. The rod electrode E1_R that is connected to the first power source PS1 arranged outside the vacuum chamber extends through the top wall 11 of vacuum chamber 1 via the vacuum space 10 to reaction chamber 2 and through the wall of the reaction chamber 2 to the first plate electrode E1_P. The first electrode is isolated from the structures of the vacuum chamber 1 and from the structures of the reaction chamber 2 through a first isolation I1. The first insulation I1 surrounds the rod electrode along its entire length and extends into the reaction chamber 2, where the first plate electrode is also isolated through the first insulation I1, such that the first insulation I1 is arranged between the bottom wall 22 of the reaction chamber 2 and the first plate electrode. The first insulation I1 thereby extends along the bottom wall 22 of the reaction chamber 2 or along the structures of the bottom wall 22 of the reaction chamber 2 such that it insulates the first plate electrode connected to the substrate holder 4 on its entire area from the structures of the reaction chamber 2. The second electrode E2 which receives the electrical power from the second power source PS2 is electrically connected to the showerhead nozzle 5. The second electrode E2 is electrically insulated from the structures of the vacuum chamber 1, i.e. in the figures from the top wall 11 of the vacuum chamber 1, and from the structures of the reaction chamber 2 through a

second insulation 12. The second electrode E2 extends from the top wall 11 of the vacuum chamber 1 through the vacuum space 10 to the reaction chamber 2 and through the top wall 21 of the reaction chamber 2 to the showerhead nozzle 5. The reaction chamber 2 may be structurally connected to the vacuum chamber 1 via the top wall 21 of the reaction chamber 2 and in that case the second electrode E2 may not extend through the vacuum space 10. The second electrode E2 is isolated from the structures of the vacuum chamber 1 and the reaction chamber 2 with a second insulation 12. The second insulation 12 is preferably also provided in the reaction chamber 2 between the showerhead nozzle 5 and the top wall 21 of the reaction chamber 2.

Figure 1 shows a plasma-enhanced atomic layer deposition apparatus according to the invention in which the first electrode E1 is arranged to form the substrate holder 4 such that the substrate 41 is provided on the surface of the first electrode E1 forming the substrate holder 4. The substrate holder 4 is thereby electrically connected to the first power source PS1. The figure 1 shows that there is one precursor gas source G arranged outside the vacuum chamber 1 and in fluid communication with the showerhead nozzle 5 so that precursor gas can be supplied through the precursor supply openings 6. However, although the figure 1 only shows one precursor gas source G, there can be several source or the gas source G may comprise different compartments to different gases such as for plasma gas. The figure 1 also shows a discharge outlet 60 through which gases are discharged out from the reaction space 20. The discharge outlet 60 is connected to a discharge pump D arranged outside the vacuum chamber 1.

Figure 2 shows another embodiment of a plasma-enhanced atomic layer deposition apparatus according to the invention in which the apparatus further comprises a separate precursor gas inlet 50 provided in connection with the wall 21, 22, 23 of the reaction chamber 2 for supplying precursor gas to the reaction zone 20a between the showerhead nozzle 5 and the substrate holder 4. Specifically, the separate precursor gas inlet 50 is arranged at the bottom wall 22 of the reaction chamber 2 in this embodiment. The precursor gases supplied from a precursor gas source G through the separate precursor gas inlet 50 flow through the reaction zone 20a as a crossflow and are discharged through the discharge outlet 60.

Figure 3 shows yet another a plasma-enhanced atomic layer deposition apparatus according to the invention in which the first electrode E1 in connection with the substrate holder 4 is part of the substrate holder 4 but not forming the

substrate holder 4. The substrate holder 4 is in contact with the first electrode E1 which is provided as a first plate electrode in connection with the substrate holder 4. The figure 3 also shows that the second electrode E2 in connection with the showerhead nozzle 5 is not integral with the showerhead nozzle 5 although in contact with the showerhead nozzle 5 between the showerhead nozzle and the top wall 21 of the reaction chamber 2. The second electrode E2 is separated from the top wall 21 of the reaction chamber 2 with a second insulation I2. The figure 3 also shows that the discharge outlet 60 can be provided at the side wall 23 of the reaction chamber 2.

10 The invention has been described above with reference to the examples shown in the figures. However, the invention is in no way restricted to the above examples but may vary within the scope of the claims.

CLAIMS

1. A plasma-enhanced atomic layer deposition apparatus for processing a surface of a substrate (41) successively with at least a first precursor gas and a second precursor gas according to principles of atomic layer deposition, the apparatus comprising:
- 5 a vacuum chamber (1) having a top wall (11), a bottom wall (12) and at least one side wall (13), said walls (11, 12, 13) of the vacuum chamber (1) forming a vacuum space (10) inside the vacuum chamber (1),
- 10 a reaction chamber (2) arranged inside the vacuum chamber (1), the reaction chamber (2) having a top wall (21), a bottom wall (22) and at least one side wall (23), said walls (21, 22, 23) of the reaction chamber (2) forming a reaction space (20) inside the reaction chamber (2),
- a substrate holder (4) arranged in the reaction chamber (2) for supporting a substrate (41) during the atomic layer deposition, and
- 15 a showerhead nozzle (5) arranged in the reaction chamber (2) opposite the substrate holder (4) such that a reaction zone (20a) is formed between the showerhead nozzle (5) and the substrate holder (4) in the reaction space (20), the showerhead nozzle (5) comprising precursor supply openings (6) through which precursor gases are supplied to the reaction zone (20a),
- 20 **characterized** in that the apparatus further comprising
- a first power source (PS1) electrically connected to the substrate holder (4), and
- a second power source (PS2) electrically connected to the showerhead nozzle (5),
- 25 said first power source (PS1) and second power source (PS2) are arranged outside the vacuum chamber (1).
2. A plasma-enhanced atomic layer deposition apparatus according to claim 1, **characterized** in that
- 30 the first power source (PS1) is an RF power source and the second power source (PS2) is an RF power source, or
- the first power source (PS1) is a DC power source and the second power source (PS2) is an RF power source.
- 35 3. A plasma-enhanced atomic layer deposition apparatus according to claim 1 or 2, **characterized** in that the apparatus further comprises a first

electrode (E1) and a second electrode (E2), which are independently controlled separate electrodes.

5 4. A plasma-enhanced atomic layer deposition apparatus according to claim 3, **characterized** in that the first power source (PS1) arranged outside the vacuum chamber (1) is electrically connected to the substrate holder (4) via the first electrode (E1), wherein said first electrode (E1) is arranged to extend through the wall (11, 12, 13) of the vacuum chamber (1) to the substrate holder (4) via the vacuum space (10) of the vacuum chamber (1) and through the
10 wall (11, 12, 13) of the reaction chamber (2).

5. A plasma-enhanced atomic layer deposition apparatus according to claim 4, **characterized** in that the first electrode (E1) comprises a first plate electrode (E1_P) having an electrical connection with the substrate holder (4)
15 and extends parallel to a support surface of the substrate holder (4) at which the substrate (41) is placed during deposition.

6. A plasma-enhanced atomic layer deposition apparatus according to claim 5, **characterized** in that the first plate electrode (E1_P) is arranged
20 inside the reaction chamber (2).

7. A plasma-enhanced atomic layer deposition apparatus according to claim 5 or 6, **characterized** in that the first electrode (E1) further comprises a rod electrode (E1_R) which extends through the vacuum space (10) of
25 the vacuum chamber (1) and through the wall (11, 12, 13) of the reaction chamber (2) and is connected to the plate electrode (PE1).

8. A plasma-enhanced atomic layer deposition apparatus according to any of claims 4-7, **characterized** in that the substrate holder (4) is at least
30 partly formed of the first electrode (E1).

9. A plasma-enhanced atomic layer deposition apparatus according to any previous claim, **characterized** in that the second power source (PS2) arranged outside the vacuum chamber (1) is electrically connected to the
35 showerhead nozzle (5) via the second electrode (E2), wherein said second electrode (E2) is arranged to extend through the wall (11, 12, 13) of the vacuum

chamber (1) to the showerhead nozzle (5) through the wall (11, 12, 13) of the reaction chamber (2).

10. A plasma-enhanced atomic layer deposition apparatus according to
5 any previous claim, **characterized** in that the showerhead nozzle (5) comprises the second electrode (E2) as an integral part of the showerhead nozzle (5).

11. A plasma-enhanced atomic layer deposition apparatus according to
10 any previous claim, **characterized** in that the first power source (PS1) connected to the first electrode (E1) and the second power source (PS2) connected to the second electrode (E2) are arranged outside the vacuum chamber (1) on the side of the top wall (11) side of the vacuum chamber (1).

12. A plasma-enhanced atomic layer deposition apparatus according to
15 any previous claim, **characterized** in that the showerhead nozzle (5) is arranged in connection with the top wall (21) of the reaction chamber (2) and the substrate holder (4) is arranged in connection with the bottom wall (22) of the reaction chamber (2), the reaction zone (20a) formed between the showerhead
20 nozzle (5) and the substrate holder (4) has a height from an output face of the showerhead nozzle (5) to a top surface of the substrate holder (4), said height is between 10 mm – 40 mm.

13. A plasma-enhanced atomic layer deposition apparatus according to
25 any previous claim, **characterized** in that the reaction space (20) is provided with a plasma grid (8), said plasma grid (8) is arranged in the reaction zone (20a) closer to the showerhead nozzle (5) than to the substrate holder (4).

14. A plasma-enhanced atomic layer deposition apparatus according to
30 any of claims 3-13, **characterized** in that the apparatus comprises
a first insulation (I1) such that the first electrode (E1) is electrically separated from structures of the reaction chamber (2) through the first insulation (I1), and
a second insulation (I2) such that the second electrode (E2) is
35 electrically separated from structures of the reaction chamber (2) through the second insulation (I2).

15. A plasma-enhanced atomic layer deposition apparatus according to any previous claim, **characterized** in that the apparatus further comprises at least one precursor gas source (G) arranged outside the vacuum chamber (1) and in fluid connection with the showerhead nozzle (5) for supplying precursor gases through the supply openings (6) to the reaction zone (20a).

16. A plasma-enhanced atomic layer deposition apparatus according to any previous claim, **characterized** in that the apparatus further comprises a separate precursor gas inlet (50) provided in connection with the wall (21, 22, 23) of the reaction chamber (2) for supplying precursor gas to the reaction zone (20a) between the showerhead nozzle (5) and the substrate holder (4).

17. A plasma-enhanced atomic layer deposition apparatus according to any previous claim, **characterized** in that the apparatus further comprises a discharge outlet (60) provided in connection with the wall (21, 22, 23) of the reaction chamber (2) for discharging precursor gases out from the reaction space (20), the discharge outlet (60) is connected to a discharge pump (D) outside the vacuum chamber (1).

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