

PLASMA ASSISTED DEPOSITION APPARATUS AND METHOD OF FORMING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of priority of Singapore application No. 10201900235W filed January 10, 2019, the contents of it being hereby incorporated by reference in its entirety for all purposes.

TECHNICAL FIELD

[0002] Various aspects of this disclosure relate to a plasma assisted deposition apparatus. Various aspects of this disclosure relate to a method of forming a plasma assisted deposition apparatus.

BACKGROUND

[0003] Atomic layer deposition (ALD) is a well-established and proven chemical vapor deposition (CVD) method in depositing dielectric, metal, and semiconductor thin films on a semiconductor substrate in the fabrication of integrated circuits (IC). The process involves introduction of two reactive gases separately at different times. Firstly, the surface of a semiconductor wafer is properly cleaned to support absorption of gaseous species. The cleaned wafer is subsequently placed onto the wafer stage. Then, the first reactive gas is introduced to the chamber to allow a monolayer of gas species to be absorbed onto the wafer surface. The chamber is vacuumed to remove all remaining gas before introducing the second gas. The second gas reacts with the first gas that is absorbed on the wafer surface to form a monolayer of solid film. This cycle is repeated until the film thickness on the wafer surface reaches the desired thickness.

[0004] The ALD process may be performed purely by thermal activation, or by plasma assisted activation of chemical species. Plasma-assisted ALD is commonly used by industry as plasma facilitates to lower the deposition temperature, a critical requirement in fabricating most of the integrated circuits (ICs). Merits of low temperature film deposition includes reduction of damage

to the circuits by uncontrolled dopant diffusion, lower resultant film stress due to differences of thermal expansion coefficient (CTE) with underlying layer, reduction in the inter-mixing or reacting with underlying layer, and reduction of substrate warpage.

[0005] Application of direct plasma to substrate surface in activating reactive species should be, in general, prevented or reduced as the plasma can cause charge-induced damages to the devices on the substrate. The most common method in introducing plasma to the substrate surface includes generating plasma at a distance from the substrate.

SUMMARY

[0006] Various embodiments may relate to a plasma assisted deposition apparatus. The plasma assisted deposition apparatus may include a chamber. The chamber may include a radio frequency (RF) electrode configured to generate plasma. The chamber may also include a stage for holding a substrate. The chamber may further include a shadow-plate between the electrode and the stage. The plasma assisted deposition apparatus may additionally include a vacuum system configured to generate a vacuum in the chamber. The plasma assisted deposition apparatus may also include one or more gas inlets configured to introduce one or more gases into the chamber. The radio frequency (RF) electrode may be a mesh including a plurality of elongate members. The shadow-plate may be a further mesh including a plurality of further elongate members aligned with the plurality of elongate members of the radio frequency (RF) electrode.

[0007] Various embodiments may relate to a method of forming a plasma assisted deposition apparatus. The method may include forming a chamber. The chamber may include a radio frequency (RF) electrode configured to generate plasma. The chamber may also include a stage for holding a substrate. The chamber may additionally include a shadow-plate between the electrode and the stage. The method may further include providing a vacuum system configured to generate a vacuum in the chamber. The method may also include providing one or more gas inlets configured to introduce one or more gases into the chamber. The radio frequency (RF) electrode may be a mesh including a plurality of elongate members. The shadow-plate is a further mesh including a plurality of further elongate members aligned with the plurality of elongate members of the radio frequency (RF) electrode.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The invention will be better understood with reference to the detailed description when considered in conjunction with the non-limiting examples and the accompanying drawings, in which:

FIG. 1 is a schematic showing the cross-sectional side view of a conventional plasma-enhanced atomic layer deposition (ALD) apparatus.

FIG. 2 is a schematic showing the cross-sectional side view of another conventional plasma-enhanced atomic layer deposition (ALD) apparatus.

FIG. 3 is a general illustration of a plasma assisted deposition apparatus according to various embodiments.

FIG. 4 is a general illustration of a method of forming a plasma assisted deposition apparatus according to various embodiments.

FIG. 5A is a schematic showing the cross-sectional side view of a plasma assisted deposition apparatus according to various embodiments.

FIG. 5B is a schematic showing the bottom view of the electrode according to various embodiments.

FIG. 5C is a schematic showing the cross-sectional side view of the electrode across line A-B shown in FIG. 5B according to various embodiments.

FIG. 5D is another schematic showing the cross-sectional side view of the electrode across line A-B shown in FIG. 5B according to various other embodiments.

FIG. 5E is a schematic showing the bottom view of a shadow-plate according to various embodiments.

FIG. 5F is a schematic showing the cross-sectional side view of the shadow-plate, the lower part of the top plate, and the electrode according to various embodiments.

FIG. 6A is a schematic showing the bottom view of the electrode according to various other embodiments.

FIG. 6B is a schematic showing the cross-sectional side view of the electrode across line E-F shown in FIG. 6A according to various embodiments.

FIG. 6C is a schematic showing the bottom view of the shadow-plate according to various other embodiments.

FIG. 6D is a schematic showing the cross-sectional side view of the shadow-plate across line G-H shown in FIG. 6C according to various embodiments.

FIG. 7A is a schematic illustrating the movement of ions in the plasma in a conventional reactor.

FIG. 7B is a schematic illustrating the operation of the plasma assisted apparatus according to various embodiments.

DETAILED DESCRIPTION

[0009] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. Other embodiments may be utilized and structural, and logical changes may be made without departing from the scope of the invention. The various embodiments are not necessarily mutually exclusive, as some embodiments can be combined with one or more other embodiments to form new embodiments.

[0010] Embodiments described in the context of one of the methods or apparatuses is analogously valid for the other methods or apparatuses. Similarly, embodiments described in the context of a method are analogously valid for an apparatus, and vice versa.

[0011] Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments. Features that are described in the context of an embodiment may correspondingly be applicable to the other embodiments, even if not explicitly described in these other embodiments. Furthermore, additions and/or combinations and/or alternatives as described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

[0012] The word "over" used with regards to a deposited material formed "over" a side or surface, may be used herein to mean that the deposited material may be formed "directly on", e.g. in direct contact with, the implied side or surface. The word "over" used with regards to a deposited material formed "over" a side or surface, may also be used herein to mean that the

deposited material may be formed "indirectly on" the implied side or surface with one or more additional layers being arranged between the implied side or surface and the deposited material. In other words, a first layer "over" a second layer may refer to the first layer directly on the second layer, or that the first layer and the second layer are separated by one or more intervening layers.

[0013] In the context of various embodiments, the articles "a", "an" and "the" as used with regard to a feature or element include a reference to one or more of the features or elements.

[0014] In the context of various embodiments, the term "about" or "approximately" as applied to a numeric value encompasses the exact value and a reasonable variance.

[0015] As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0016] FIG. 1 is a schematic showing the cross-sectional side view of a conventional plasma-enhanced atomic layer deposition (ALD) apparatus. The ALD system includes a chamber 1 to house a wafer holding stage 2, a plasma generation tube 3 attached to the chamber 1 above the wafer stage 2, and a vacuum system 4. Plasma is generated by applying radio frequency (RF) electric power to an inductive coil 5 wound around the plasma generation tube 3. Inert and reactive gases can be introduced at the upstream of plasma generation tube 3 using gas inlet 6a or directly into the reactor using gas inlet 6b. Typically, inert gas is introduced into the plasma generation tube 3 and reactive gases are introduced directly into the chamber 1. Introduction of reactive gases directly into plasma by gas inlet 6a causes higher degree of dissociation which may be undesirable in most thin film formation on wafer 7. Therefore, in most processes, reactive gas is introduced into the reaction chamber via gas inlet 6b. The reactive gases may still get dissociated (to a certain lesser degree) by the gas phase collisions with ionic species coming from the plasma region. The inductive coil 5 is connected to a RF matching circuit 9, which in turn is connected to a RF power generator 10. The ALD system also includes a gate valve 8.

[0017] The plasma generation tube 3 is positioned at a considerable distance from the wafer stage 2. This reduces chances of ionic species directly reaching the wafer 7, thereby causing charge-up damages. However, placing the plasma generation tube 3 away from wafer stage 2 may result in a larger reactor volume, which in turn require a longer vacuum time to remove all remaining reactive gases species in the reactor, as well as a longer time for the pressure to stabilize with the introduction of a new gas into the chamber.

[0018] FIG. 2 is a schematic showing the cross-sectional side view of another conventional plasma-enhanced atomic layer deposition (ALD) apparatus. The reactor 11 includes a wafer stage 12, a plasma generation cavity 13, a filter 14 placed between plasma generation cavity 13 and the wafer stage 12, and a vacuum system 15. The wafer stage 12 is configured to hold a wafer 16. The apparatus also includes a gate valve 17. A gas inlet 18a introduces gas within the plasma generation cavity 13, while another gas inlet 18b introduces gas outside of the plasma generation cavity 13.

[0019] A plasma is generated by applying a RF current to an RF electrode 21 placed inside the plasma generation cavity 13. The electrode 21 is connected to a matching circuit 19, which is in turn connected to a power generator 20. FIG. 2 shows that the plasma is generated by a capacitive coupling mechanism. However, the plasma may instead be generated by an inductive coil placed inside the plasma generation cavity 13.

[0020] During the operation, plasma is generated in the plasma generation cavity 13 before passing through the filter 14. The ionic species generated in the plasma has to go through the filter 14, and whether the generated ionic species can go through the filter is determined by the diameter and height of the holes in the filter. The collisions of the ionic species with the filter sidewalls may cause the ionic species to lose its ionic nature. Even a single collision of ionic species with the sidewall may annihilate its ionic nature. For a given system layout, the diameter and height of holes in the filter are fixed. As such, the number of ions or radicals that can reach the wafer are also predetermined. In other words, the energy of ions or radicals coming out of filter 14 are fixed. Therefore, the dissociation fraction of reactive precursors which are directly introduced into the reactor 1 is also fixed, thus limiting the flexibility in the selection of gaseous species in developing film deposition chemistries for materials development. In addition, the larger overall reactor volume that needs to be vacuumed before introduction of the second gas may cause longer vacuuming time, and therefore a lower throughput.

[0021] Various embodiments may address or mitigate various problems facing conventional apparatuses. Various embodiments may seek to address the problems of lower throughput, and/or the controllability of reactive gas dissociation.

[0022] **Lower throughput**

[0023] Throughput may be defined as the number of substrates (e.g. wafers) that can be processed per unit time. Throughput may be an important factor in the industrial processing of

semiconductor substrates or wafers. Plasma-enhanced atomic layer deposition is a slow process by nature due to two reasons. Firstly, the gases are introduced separately with a vacuuming or purging step in between. This is similar to thermal ALD. Therefore, the overall time to deposit a monolayer of film is longer compared to conventional chemical vapor deposition (CVD) in which two gases are introduced at the same time.

[0024] The purging or vacuuming time between the introduction of the two reactive gases can be reduced by decreasing the chamber volume. However, in plasma-enhanced ALD (PE-ALD) systems, this may be difficult since there should be some separation between the plasma generation region and the substrate in order to limit or prevent energetic ionic species reaching the wafer. If the ionic species hit the wafer surface, it may remove atoms or molecules absorbed on the wafer surface, resulting in non-uniform thickness of the deposited film.

[0025] A system configuration similar to that shown in FIG. 2 has been previously reported. The reported system generates plasma in a separate cavity just above the wafer surface via inductive coupling. The gas species are transported through a filter to the wafer surface. The plasma cavity and filter are spread over the entire whole wafer surface, indicating that there is a large volume for vacuuming. The distance between the filter and the wafer is shortened to reduce the volume above the wafer. However, the plasma downstream is required to flow outward from the wafer surface to a vacuum port over the plasma generation cavity. The overall volume that needs to be vacuumed is therefore become quite considerable.

[0026] In another system configuration similar to that shown in FIG. 2, a plasma is generated by capacitive coupling using a RF electrode arranged on the sidewall. As the plasma generated has to be uniformly spread throughout the plasma cavity, the cavity is required to have a reasonable height, thus making the overall volume larger. The result is that this configuration also requires a larger volume for vacuuming.

[0027] Other conventional PE-ALD tools in the market tend to have a large overall chamber volume that needs to be vacuumed. This results in a longer vacuuming time and therefor a lower throughput.

[0028] The second reason for lower throughput is that considerable time is required to generate and stabilize the plasma. During ALD film deposition, the chamber is repeatedly subjected to vacuuming and gas introduction. In order to generate a stable plasma, the gas pressure inside the

chamber has to be also stable. If the chamber volume is large, the time required for gas pressure stabilization also increases. Additional time is also required to stabilize the plasma after it is formed, especially for a large volume chamber. The time required to stabilize the gas pressure and the plasma in a large volume chamber contribute to lower throughput.

[0029] **Insufficient gaseous species available for film formation**

[0030] Most of the PE-ALD systems available or proposed in the industry include a generation region and a filter. The use of a filter above the plasma may help facilitate a reduction in the overall chamber volume as the plasma has to be otherwise generated at an area considerable away from substrate. The filter, on the other hand, may limit the energy of ions or radicals that reach the wafer processing region. Even a single collision of an ion on the filter sidewall may annihilate its ionic status and remove part of its energy. If the filter holes are small, the ions and the radicals lose more energy through repeated collisions with the sidewalls. Accordingly, for a filter with given diameter and height, the energy of ions or radicals coming out of the filter is predetermined. If the energy of ions or radicals is predetermined, the dissociation fraction of precursor gas and thereby the gas phase chemistry in the chamber is also predetermined.

[0031] Various embodiments may provide higher throughput. Various embodiments may increase the number/range of parameters of gaseous species to select from in process development.

[0032] FIG. 3 is a general illustration of a plasma assisted deposition apparatus according to various embodiments. The plasma assisted deposition apparatus may include a chamber. The chamber may include a radio frequency (RF) electrode configured to generate plasma. The chamber may also include a stage for holding a substrate (e.g. a wafer). The chamber may further include a shadow-plate between the electrode and the stage. The plasma assisted deposition apparatus may additionally include a vacuum system configured to generate a vacuum in the chamber. The plasma assisted deposition apparatus may also include one or more gas inlets configured to introduce one or more gases into the chamber. The radio frequency (RF) electrode may be a mesh including a plurality of elongate members. The shadow-plate may be a further mesh including a plurality of further elongate members aligned with the plurality of elongate members of the radio frequency (RF) electrode.

[0033] In other words, the plasma assisted deposition apparatus may include a chamber having a RF electrode, a stage and a shadow-plate. The shadow-plate may be between the RF electrode

and the stage, e.g. above the stage but below the electrode. The plasma deposition apparatus may also include a vacuum system and one or more gas inlets. Both the RF electrode and the shadow-plate may be meshes. The RF electrode mesh may be aligned with the shadow-plate mesh.

[0034] For avoidance of doubt, FIG. 3 serves to illustrate some of the feature of a plasma assisted according to various embodiments, and is not intended to limit the arrangement, size, shape etc. of the various features.

[0035] An “elongate member” or a “further elongate member” may refer to a structure having a length greater than a width of the structure. The length of the structure may also be greater than a thickness of the structure.

[0036] The plurality of further elongate members may be aligned with the plurality of elongate members such that straight lines drawn from the elongate members of the radio frequency (RF) electrode to the stage or the substrate are blocked by the further elongate members of the shadow-plate. For instance, each further elongate member of the shadow-plate may be directly below a respective elongate member of the radio frequency (RF) electrode. In various embodiments, a width of a further elongate member of the plurality of further elongate members may be equal to or greater than a width of an elongate member of the plurality of elongate members.

[0037] When the plasma assisted deposition apparatus is in operation, the wafer may be placed on the stage which is below the shadow-plate, while the shadow-plate may be below the RF electrode. The shadow-plate and the RF electrode may have the same or similar patterns with each further elongate member of the shadow-plate directly below a respective elongate member of the radio frequency (RF) electrode, such that the plurality of further elongate members of the shadow-plate are aligned with the plurality of elongate members of the RF electrode.

[0038] In various embodiments, the plurality of elongate members of the radio frequency (RF) electrode may be or may include ribbons. The further plurality of elongate members of the shadow-plate may be or may include further ribbons. A “ribbon” or a “further ribbon” may refer to a structure in which the length is greater than the width of the structure, which in turn is greater than the thickness of the structure.

[0039] In various embodiments, the plurality of elongate members of the radio frequency (RF) electrode may include a first group of straight elongate members arranged parallel to one another; and a second group of straight elongate members arranged parallel to one another and

perpendicular to the first group of straight elongate members. Each of the straight elongate members may be straight along its length. In other words, the RF electrode may be a mesh including the first group of parallel, straight elongate members crossing the second group of parallel, straight elongate members at right angles.

[0040] The pattern of the shadow-plate may be similar or correspond to the pattern of the radio frequency (RF) electrode. The plurality of further elongate members of the shadow-plate may include a first group of straight further elongate members arranged parallel to one another; and a second group of straight further elongate members arranged parallel to one another and perpendicular to the first group of straight further elongate members. Each of the straight further elongate members may be straight along its length. In other words, the first group of parallel, straight further elongate members may cross the second group of parallel, straight further elongate members at right angles.

[0041] The elongate members of the radio frequency (RF) electrode may define a plurality of holes. A hole may be defined by two neighboring elongate members from the first group and two neighboring elongate members from the second group which cross the two neighboring elongate members from the first group. In various embodiments, a size of an inner hole of the plurality of holes nearer to a center of the radio frequency (RF) electrode may be equal to a size of an outer hole further from the center of the radio frequency (RF) electrode. Distances between different pairs of neighboring elongate members may be equal to one another. In various other embodiments, a size of an inner hole of the plurality of holes nearer to a center of the radio frequency (RF) electrode may be greater than a size of an outer hole further from the center of the radio frequency (RF) electrode. A distance between a pair of neighboring elongate members nearer to the center of the RF electrode may be greater than a distance between another pair of neighboring elongate members further from the center of the radio frequency (RF) electrode. The distance may decrease from the center to the edge of the radio frequency (RF) electrode so that the radio frequency (RF) electrode may provide a plasma of greater uniformity over the surface of the wafer.

[0042] In various embodiments, the plurality of elongate members of the radio frequency (RF) electrode may include circular rings and straight elongate members connecting the circular rings. The circular rings may form a concentric arrangement centered at a center of the RF electrode and

the straight elongate members may extend radially from the center of the RF electrode to the edge or perimeter of the RF electrode. The circular rings and straight elongate members may form a circular mesh, i.e. a mesh with concentric rings.

[0043] The pattern of the shadow-plate may be similar or correspond to the pattern of the radio frequency (RF) electrode. The plurality of further elongate members of the shadow-plate may include further circular rings and further straight elongate members connecting the further circular rings. The further circular rings may form a concentric arrangement centered at a center of the shadow-plate and the further straight elongate members may extend radially from the center of the shadow-plate to the edge or perimeter of the shadow-plate. The circular rings and straight elongate members may also form a further circular mesh.

[0044] In various embodiments, a gas inlet of the one or more gas inlets may pass between two neighboring elongate members of the plurality of elongate members of the radio frequency (RF) electrode.

[0045] In various embodiments, the shadow-plate may include a metal.

[0046] In various embodiments, the shadow-plate may be connected or configured to be connected to ground.

[0047] In various other embodiments, the shadow-plate may be configured to be in an electrically floating state during operation. The shadow-plate may be in the electrically floating state to control one or more parameters of the plasma.

[0048] In yet various other embodiments, the plasma assisted deposition apparatus may be configured so that, during operation, the shadow-plate is in a floating state when the radio frequency (RF) electrode generates plasma, and the shadow-plate is in a ground state when the radio frequency (RF) electrode does not generate plasma. In other words, an electrical state of the radio frequency (RF) electrode may be switched between the ground state and the floating state during operation. In various embodiments, the electrical state may be switched at pre-determined time intervals during operation. In various embodiments, the electrical state may be switched to match with an on-off timing of the plasma.

[0049] In various embodiments, the plasma assisted deposition apparatus may include a top plate including an upper part and a lower part. The upper part may include a metal, and the lower part may include an insulator material. The upper part may be configured to be connected to a

radio frequency (RF) source via a radio frequency (RF) matching circuit. In various embodiments, the plasma assisted deposition apparatus may include the radio frequency (RF) matching circuit.

[0050] In various embodiments, the top plate may include a gas introduction system. The gas introduction system may be a shower-head type gas introduction system. The top plate may include a cavity. The top plate may also include a main gas inlet in fluidic communication with the cavity. In addition, the cavity may also be fluidic communication with at least some of the one or more gas inlets. The cavity, the main gas inlet, and the gas inlet(s) that are in fluidic communication with the cavity and which are included in the top plate may form the gas introduction system.

[0051] In various embodiments, the lower part of the top plate may include a plurality of grooves for accommodating the elongate members of the radio frequency (RF) electrode. In various other embodiments, the elongate members of the radio frequency (RF) electrode may be in contact with a planar surface of the lower part of the top plate.

[0052] FIG. 4 is a general illustration of a method of forming a plasma assisted deposition apparatus according to various embodiments. The method may include, in S1, forming a chamber. The chamber may include a radio frequency (RF) electrode configured to generate plasma. The chamber may also include a stage for holding a substrate. The chamber may additionally include a shadow-plate between the electrode and the stage. The method may further include, in S2, providing a vacuum system configured to generate a vacuum in the chamber. The method may also include, in S3, providing one or more gas inlets configured to introduce one or more gases into the chamber. The radio frequency (RF) electrode may be a mesh including a plurality of elongate members. The shadow-plate may be a further mesh including a plurality of further elongate members aligned with the plurality of elongate members of the radio frequency (RF) electrode.

[0053] In other words, the method may include forming a chamber which include an RF electrode, a shadow-plate as well as a stage. The method may also include connecting a vacuum system and one or more gas inlets to the chamber so that the vacuum system and the one or more gas inlets may be in fluidic communication with the chamber during operation.

[0054] For avoidance of doubt, the steps shown in FIG. 4 is not intended to be in sequence. For instance, step S2 may occur before, after, or at the same time as step S3.

[0055] In various embodiments, the plurality of further elongate members may be aligned with the plurality of elongate members such that straight lines drawn from the elongate members of the radio frequency (RF) electrode to the stage are blocked by the further elongate members of the shadow-plate.

[0056] In various embodiments, the plurality of elongate members of the radio frequency (RF) electrode may include ribbons. The further plurality of elongate members of the shadow-plate may include further ribbons.

[0057] In various embodiments, the plurality of elongate members of the radio frequency (RF) electrode may include a first group of straight elongate members arranged parallel to one another; and a second group of straight elongate members arranged parallel to one another and perpendicular to the first group of straight elongate members. The plurality of further elongate members of the shadow-plate may include a first group of straight further elongate members arranged parallel to one another; and a second group of straight further elongate members arranged parallel to one another and perpendicular to the first group of straight further elongate members.

[0058] In various embodiments, the elongate members of the radio frequency (RF) electrode may define a plurality of holes.

[0059] In various embodiments, a size of an inner hole of the plurality of holes nearer to a center of the radio frequency (RF) electrode may be equal to a size of an outer hole further from the center of the radio frequency (RF) electrode.

[0060] In various other embodiments, a size of an inner hole of the plurality of holes nearer to a center of the radio frequency (RF) electrode may be greater than a size of an outer hole further from the center of the radio frequency (RF) electrode.

[0061] In various embodiments, the plurality of elongate members of the radio frequency (RF) electrode may include circular rings and straight elongate members connecting the circular rings. The plurality of further elongate members of the shadow-plate may include further circular rings and further straight elongate members connecting the further circular rings.

[0062] In various embodiments, a width of a further elongate member of the plurality of further elongate members may be greater than a width of an elongate member of the plurality of elongate members.

[0063] In various embodiments, a gas inlet of the one or more gas inlets may pass between two neighboring elongate members of the plurality of elongate members of the radio frequency (RF) electrode.

[0064] In various embodiments, the shadow-plate may include a metal.

[0065] In various embodiments, the shadow-plate may be configured to be connected to ground. In various other embodiments, the shadow-plate may be configured to be in an electrically floating state during operation. In yet various other embodiments, the plasma assisted deposition apparatus is configured so that, during operation, the shadow-plate is in a floating state when the radio frequency (RF) electrode generates plasma, and the shadow-plate is in a ground state when the radio frequency (RF) electrode does not generate plasma.

[0066] In various embodiments, the method may further include forming or providing a top plate including an upper part and a lower part. The upper part may include a metal. The lower part may include an insulator material.

[0067] In various embodiments, the upper part may be in electrical connection to the radio frequency (RF) electrode. The upper part may be configured to be connected to a radio frequency (RF) source via a radio frequency (RF) matching circuit.

[0068] In various embodiments, the top plate may include a gas introduction system. The gas introduction system may be a shower-head type gas introduction system. The top plate may include a cavity. The top plate may also include a main gas inlet in fluidic communication with the cavity. In addition, the cavity may also be fluidic communication with at least some of the one or more gas inlets. The cavity, the main gas inlet, and the gas inlet(s) that are in fluidic communication with the cavity and which are included in the top plate may form the gas introduction system.

[0069] In various embodiments, the lower part of the top plate may include a plurality of grooves for accommodating the elongate members of the radio frequency (RF) electrode. In various other embodiments, the elongate members of the radio frequency (RF) electrode may be in contact with a planar surface of the lower part of the top plate.

[0070] FIG. 5A is a schematic showing the cross-sectional side view of a plasma assisted deposition apparatus 100 according to various embodiments. The apparatus 100 may include a reactor or chamber 101, and a stage or wafer stage 102 included in the reactor or chamber 101. The wafer stage 102 may include embedded heaters which are not shown in FIG. 5A for simplicity.

The apparatus 100 may also include a radio frequency (RF) electrode 103 configured to generate plasma via capacitive coupling. The RF electrode 103 may be a mesh. The apparatus 100 may additionally include a vacuum system 104.

[0071] The apparatus 100 may further include a top plate. The top plate may include an upper part 105a and a lower part 105b. The upper part 105a may be made of a metal, while the lower part 105b may be made of an insulator material, such as ceramic. The upper part 105a may be sufficiently thick to withstand the pressure difference between inside of the chamber 101 and the outside atmospheric pressure. A radio frequency (RF) power source 106 may be connected to the center of the upper part 105a of the top plate via a radio frequency (RF) current matching circuit 107. The mesh-type electrode 103 may be electrically connected to the upper part 105a of the top plate along or at its outer perimeter.

[0072] The top plate may also include a shower-head type gas introduction system. The gas introduction system may include a cavity 108, a main gas inlet 110, and gas inlets 109. First, a gas may be introduced into the cavity 108 located inside the top plate via the main gas inlet 110. The gas may then travel from the cavity 108 into the chamber 101 via the smaller gas inlets 109 to introduce gas into the chamber 101.

[0073] FIG. 5B is a schematic showing the bottom view of the electrode 103 according to various embodiments. The electrode 103 may include a suitable metal such as copper. Plasma may be generated upon application of a radio frequency (RF) current to the electrode 103. The RF current may be provided by the RF power source 106 via the matching circuit 107. The mesh-type electrode 107 may include a first group of straight elongate members, e.g. ribbons 103a, b etc. arranged parallel to one another; and a second group of straight elongate members arranged parallel to one another and perpendicular to the first group of straight elongate members 103a, b etc. The elongate members may define a plurality of holes and the lower part 105b of the top plate may be seen through the holes, as shown in FIG. 5B. The width of each elongate member or ribbon may be of any suitable value, e.g. any value in the range from 1 mm to 20 mm. The distance between neighboring elongate members may be of any suitable value, and may be dependent on the width of the elongate members or ribbons.

[0074] In various embodiments, the distance between neighboring elongate members or ribbons may be constant, such as that shown in FIG. 5B. A size of an inner hole of the plurality of

holes nearer to a center of the RF electrode 103 may be equal to a size of an outer hole further from the center of the RF electrode 103.

[0075] In various embodiments, a distance between a pair of neighboring elongate members nearer to the center of the RF electrode 103 may be greater than a distance between another pair of neighboring elongate members further from the center of the RF electrode 103. A size of an inner hole of the plurality of holes nearer to a center of the RF electrode may be greater than a size of an outer hole further from the center of the RF electrode. The distance may decrease from the center to the edge of the RF electrode 103 so that the radio frequency (RF) electrode may provide a plasma of greater uniformity over the surface of the wafer.

[0076] FIG. 5C is a schematic showing the cross-sectional side view of the electrode 103 across line A-B shown in FIG. 5B according to various embodiments. As shown in FIG. 5C, the elongate members 103a, 103b etc. of the radio frequency (RF) electrode may be in contact with a planar or flat surface of the lower part 105b of the top plate. FIG. 5D is another schematic showing the cross-sectional side view of the electrode 103 across line A-B shown in FIG. 5B according to various other embodiments. As shown in FIG. 5D, the lower part 105b of the top plate may include a plurality of grooves for accommodating the elongate members 103a, 103b etc. of the radio frequency (RF) electrode. The elongate members 103a, 103b etc. may be embedded in the lower part 105b.

[0077] The apparatus 100 may also include a shadow-plate 111. FIG. 5E is a schematic showing the bottom view of a shadow-plate 111 according to various embodiments. FIG. 5F is a schematic showing the cross-sectional side view of the shadow-plate 111, the lower part 105b of the top plate, and the electrode 103 according to various embodiments. The profile of the shadow-plate in FIG. 5F may correspond to that indicated by line C – D in FIG. 5E. The shadow plate 111 may also be a mesh placed below the RF electrode 103. The shadow plate 111 may be separated from the RF electrode, e.g. by a few millimeters. The shadow plate 111 may be attached or fixed to the reactor or chamber 101, i.e. the sidewalls of the reactor or chamber 101. The separation between the RF electrode 103 and the shadow plate 111 may be of any suitable value, e.g. any value in the range from 5mm to 10mm. The further elongate members or further ribbons 111a, 111b, ... etc. of the shadow plate 111 may be aligned with the elongate members or ribbons 103a, 103b of the RF electrode 103. For instance, the further elongate member or ribbon 111a may be aligned to be

directly below the elongate member or ribbon 103a, while the further elongate member or ribbon 111b may be aligned to be directly below the elongate member or ribbon 103b.

[0078] The shadow-plate 111 may be grounded electrically in various embodiments. In various other embodiments, the shadow-plate 111 may be set at an electrically floating state in order to control some of parameters of the generated plasma.

[0079] The apparatus 100 may further include one or plurality of gas inlets 112 leading to the reaction chamber 101. Gas introduced to the reaction chamber 101 may be fed into the reaction chamber 101 using a circular tube 113 having a diameter larger than the diameter of the wafer stage 102.

[0080] As mentioned earlier, the wafer stage 102 in the chamber 101 may include embedded heaters to heat the substrate or wafer 114. The wafer stage 102 may include a heated stage 115 and an electrostatic chuck 116. The distance between the stage 102 and the top side of the shadow plate 111 may be of any suitable value, e.g. of any value in the range from 10 mm to about 20 mm. Various embodiments may seek to keep this distance as small as possible so that overall reactor volume gets smaller, which may in turn help to reduce the reactor vacuum time. The reactor or chamber 101 may be defined by a base, sidewalls as well as cover plate 118.

[0081] FIG. 6A is a schematic showing the bottom view of the electrode 103 according to various other embodiments. FIG. 6B is a schematic showing the cross-sectional side view of the electrode 103 across line E-F shown in FIG. 6A according to various embodiments.

[0082] In various embodiments, the plurality of elongate members of the radio frequency (RF) electrode may include circular rings 103a, 103b etc., and straight elongate members connecting the circular rings. The circular rings 103a, 103b etc. may form a concentric arrangement centered at a center of the RF electrode 103 and the straight elongate members may extend radially from the center of the RF electrode 103 to the edge or perimeter of the RF electrode 103. The circular rings and straight elongate members may form a circular mesh, i.e. a mesh with concentric rings.

[0083] The circular rings 103a, 103b etc. and/or the straight elongate members may include a suitable metal. For instance, the circular rings 103a, 103b etc. and/or the straight elongate members may be made of copper plates.

[0084] There may be any suitable number of circular rings. For instance, the number of circular rings may range from 2 to 10. The number of circular rings may be dependent on the diameter of

the lower part 105b of the top plate. In order to align with the electrode 103 with circular rings, the shadow plate 111 may also include circular rings. FIG. 6C is a schematic showing the bottom view of the shadow-plate 111 according to various other embodiments. FIG. 6D is a schematic showing the cross-sectional side view of the shadow-plate 111 across line G-H shown in FIG. 6C according to various embodiments. The shadow-plate 111 may include further circular rings 111a, 111b etc. and further straight elongate members connecting the further circular rings 111a, 111b etc. The circular rings may be aligned with the further circular rings, and the straight elongate members may be aligned with the further straight elongate members. As shown in FIG. 6D, the circular rings 103a, 103b etc. may be directly above the further circular rings 111a, 111b etc.

[0085] The shadow plate 111 may be separated from the RF electrode, e.g. by a few millimeters. The separation between the RF electrode 103 and the shadow plate 111 may be of any suitable value, e.g. any value in the range from 5mm to 10mm. Other features such as shadow plate material, electrical status of shadow plate and the role of shadow plates may be similar to that described above.

[0086] FIG. 7A is a schematic illustrating the movement of ions in the plasma in a conventional reactor. In a plasma generation system (applicable to both capacitively coupled or inductively coupled systems), ions may be generated by collisions of accelerated electrons with neutral atoms, and this happens at the close vicinity of the RF electrode 31 (e.g. placed within plasma generation cavity 32), generally within sub-millimeter range and depending on the gas pressure. These ions thereafter drift throughout the chamber by diffusion or convection process. The movement of ions are denoted by reference numeral 33. The ions in the conventional system may be subjected to many collisions before reaching the reaction chamber. Ions generated in the plasma may lose its ionic state after a couple of collisions with neutral gas species or with the sidewall of reactor or filter 34. Therefore, all or most of the gaseous species reaching the wafer may be in the form of neutral radicals or neutral gases.

[0087] FIG. 7B is a schematic illustrating the operation of the plasma assisted apparatus 100 according to various embodiments. Various embodiments may include a shadow plate 111 that prevent or reduce the likelihood of ions generated at the vicinity of the RF electrodes 103 from directly coming onto the wafer surface. Ions generated are essentially subjected to multiple collisions with the shadow plate 111, the top plate 105b, or other gaseous species before reaching

the wafer. Ions may lose their ionic state due to these multiple collisions. The arrangement of the RF electrode and the shadow-plate may reduce the likelihood or prevent ions from reaching the wafer, even when the chamber or reactor has a small volume. Various embodiments may provide the same gaseous environment as that of a conventional system with a filter, but with a smaller chamber or reactor volume. The patterns of both the RF electrode and the shadow-plate, as well as the alignment of the RF electrode and the shadow-plate may increase the number of collisions of the ions, thus greatly reducing the likelihood or preventing ions from reaching the wafer.

[0088] Further, the dissociation degree of reactive gases may be increased by introducing reactive gases through the gas inlets 109 in the top plate 105. The dissociated radicals may be subjected to gas-phase collisions while drifting towards the wafer 114. Each gas phase collision may cause energy transfer from high-energy radicals to neutral gas molecules which are introduced to the downstream through the gas inlet 113. Also, some reactive gas radicals may recombine with other suitable gas molecules introduced downstream before reaching the wafer 114. Accordingly, by controlling the reaction chamber pressure, the number of gas phase collisions can be adjusted until the desired gas species generated reach the wafer. This gas phase radical selection capability may help provide greater flexibility in the fabrication of materials, and may also provide more opportunities in the research of materials.

[0089] While the invention has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. The scope of the invention is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

Claims

1. A plasma assisted deposition apparatus comprising:
 - a chamber comprising:
 - a radio frequency (RF) electrode configured to generate plasma;
 - a stage for holding a substrate;
 - a shadow-plate between the electrode and the stage;
 - a vacuum system configured to generate a vacuum in the chamber;
 - one or more gas inlets configured to introduce one or more gases into the chamber;
 - wherein the radio frequency (RF) electrode is a mesh comprising a plurality of elongate members; and
 - wherein the shadow-plate is a further mesh comprising a plurality of further elongate members aligned with the plurality of elongate members of the radio frequency (RF) electrode.
2. The plasma assisted deposition apparatus according to claim 1,
 - wherein the plurality of further elongate members is aligned with the plurality of elongate members such that straight lines drawn from the elongate members of the radio frequency (RF) electrode to the stage are blocked by the further elongate members of the shadow-plate.
3. The plasma assisted deposition apparatus according to claim 1 or claim 2
 - wherein the plurality of elongate members of the radio frequency (RF) electrode comprises ribbons; and
 - wherein the further plurality of elongate members of the shadow-plate comprises further ribbons.
4. The plasma assisted deposition apparatus according to any one of claims 1 to 3,

wherein the plurality of elongate members of the radio frequency (RF) electrode comprises a first group of straight elongate members arranged parallel to one another; and a second group of straight elongate members arranged parallel to one another and perpendicular to the first group of straight elongate members; and wherein the plurality of further elongate members of the shadow-plate comprises a first group of straight further elongate members arranged parallel to one another; and a second group of straight further elongate members arranged parallel to one another and perpendicular to the first group of straight further elongate members.

5. The plasma assisted deposition apparatus according to any one of claims 1 to 4,
wherein the elongate members of the radio frequency (RF) electrode define a plurality of holes.
6. The plasma assisted deposition apparatus according to claim 5,
wherein a size of an inner hole of the plurality of holes nearer to a center of the radio frequency (RF) electrode is equal to a size of an outer hole further from the center of the radio frequency (RF) electrode.
7. The plasma assisted deposition apparatus according to claim 5,
wherein a size of an inner hole of the plurality of holes nearer to a center of the radio frequency (RF) electrode is greater than a size of an outer hole further from the center of the radio frequency (RF) electrode.
8. The plasma assisted deposition apparatus according to any one of claims 1 to 3,
wherein the plurality of elongate members of the radio frequency (RF) electrode comprises circular rings and straight elongate members connecting the circular rings; and
wherein the plurality of further elongate members of the shadow-plate comprises further circular rings and further straight elongate members connecting the further circular rings.

9. The plasma assisted deposition apparatus according to any one of claims 1 to 8,
wherein a width of a further elongate member of the plurality of further elongate members is greater than a width of an elongate member of the plurality of elongate members.
10. The plasma assisted deposition apparatus according to any one of claims 1 to 9,
wherein a gas inlet of the one or more gas inlets passes between two neighboring elongate members of the plurality of elongate members of the radio frequency (RF) electrode.
11. The plasma assisted deposition apparatus according to any one of claims 1 to 10,
wherein the shadow-plate comprises a metal.
12. The plasma assisted deposition apparatus according to any one of claims 1 to 11,
wherein the shadow-plate is configured to be connected to ground.
13. The plasma assisted deposition apparatus according to any one of claims 1 to 12,
wherein the shadow-plate is configured to be in an electrically floating state during operation.
14. The plasma assisted deposition apparatus according to any one of claims 1 to 13,
wherein the plasma assisted deposition apparatus is configured so that, during operation, the shadow-plate is in a floating state when the radio frequency (RF) electrode generates plasma, and the shadow-plate is in a ground state when the radio frequency (RF) electrode does not generate plasma.
15. The plasma assisted deposition apparatus according to any one of claims 1 to 14, further comprising:
a top plate comprising an upper part and a lower part;

wherein the upper part comprises a metal; and
wherein the lower part comprises an insulator material.

16. The plasma assisted deposition apparatus according to claim 15,
wherein the upper part is in electrical connection to the radio frequency (RF) electrode; and
wherein the upper part is configured to be connected to a radio frequency (RF) source via a radio frequency (RF) matching circuit.
17. The plasma assisted deposition apparatus according to claim 15 or claim 16,
wherein the top plate comprises a gas introduction system.
18. The plasma assisted deposition apparatus according to any one of claims 15 to 17,
wherein the lower part of the top plate comprises a plurality of grooves for accommodating the elongate members of the radio frequency (RF) electrode.
19. The plasma assisted deposition apparatus according to any one of claims 15 to 17,
wherein the elongate members of the radio frequency (RF) electrode are in contact with a planar surface of the lower part of the top plate.
20. A method of forming a plasma assisted deposition apparatus, the method comprising:
forming a chamber comprising:
a radio frequency (RF) electrode configured to generate plasma;
a stage for holding a substrate;
a shadow-plate between the electrode and the stage;
providing a vacuum system configured to generate a vacuum in the chamber;
providing one or more gas inlets configured to introduce one or more gases into the chamber;
wherein the radio frequency (RF) electrode is a mesh comprising a plurality of elongate members; and

wherein the shadow-plate is a further mesh comprising a plurality of further elongate members aligned with the plurality of elongate members of the radio frequency (RF) electrode.