INDUCTIVELY COUPLED COIL AND INDUCTIVELY COUPLED APPARATUS USING THE SAME

FIELD OF THE INVENTION

The present invention relates to fittings for a semiconductor wafer processing equipment, and more specifically relates to an inductively coupled coil and an inductively coupled apparatus using the inductively coupled coil.

BACKGROUND OF THE INVENTION

At present, with the fast developments of the electronic technology, it is required that the integration level of the integrated circuits be higher and higher, which needs the enterprises that manufacture the integrated circuits to increasingly improve their capability to process the semiconductor wafer. A plasma apparatus has been widely applied to the manufacturing process of IC (integrated circuit) or MEMS (micro-electronic mechanical system) device. Meanwhile, The ICP (inductively coupled plasma) apparatus has been widely applied to processes such as etching. Under low pressure, after a reaction gas is excited by RF (radio frequency) power, ionization is produced to generate a plasma. The plasma is composed of a large number of active particles such as electrons, ions, atoms and molecules in excited state and free radical. There are various physical and chemical reactions occurred on the surface to be etched and volatile resultant is produced, and accordingly the surface performance is changed.

The structure of the inductively coupled plasma apparatus as shown in Fig. 1 is now used by most of semiconductor etching equipments. In the course of semiconductor processing, the process gas introduced into a reaction chamber 3 through a gas inlet 2 located at the center of a dielectric window 1 is ionized by an inductively coupled coil 4 on the dielectric window 1, and a plasma is produced which is used to etch the surface of a wafer 5. In the system, a molecular pump is used to pump the gas in the reaction chamber 3 out through a gas outlet 6. In this process, the radio frequency power that can ionize the gas and generate the plasma is from the inductively coupled coil 4. At present, a radio frequency at 13.56 MHz is applied to the inductively coupled coil 4 so as to excite it in

such a manner that there is a radio frequency current flowing in the inductively coupled coil 4 and accordingly a varying magnetic field is generated. According to the Faraday's Law of Electromagnetic Induction, this varying magnetic field will induce an electric field and accordingly the reaction gas in the reaction chamber 3 is ionized to produce plasma. The excited plasma reacts with the work piece in the reaction chamber 3, so that the work piece is etched or a material is deposited on the work piece. Normally, the work piece is a semiconductor wafer with a circular plane. The asymmetry of the gas pumping or the reaction chamber 3 normally will cause the asymmetry of particle density, temperature and flux in the reaction chamber 3. The asymmetric gas flow will cause the asymmetric plasma conductivity. The asymmetric plasma conductivity will cause the non-uniform power deposition and accordingly the non-uniform electron-impact ionization will be caused. With the size of the wafer 5 increasing, the volume of the reaction chamber 3 also increases correspondingly, and the non-uniformity of plasma density distribution between the edge and the center of the reaction chamber 3 will be more obvious. Therefore, most of etching equipments now encounter the problem of non-uniform etching rate , which brings great adverse influence on the manufacturing process of semiconductors.

In order to obtain a relatively uniform etching rate on the surface to be etched, a relatively uniform plasma density distribution above the wafer 5 in the reaction chamber 3 is needed, i.e. a relatively uniform plasma distribution above the wafer 5 is obtained so that the etching quality can be improved.

As shown in Fig. 2, the inductively coupled coil 4 commonly used adopts a planar spiral structure and the plasma excited by it is very non-uniform. Because the electromagnetic field at the center of the reaction chamber excited by this inductively coupled coil is relatively strong, the plasma density produced there is large. The periphery area with low plasma density can only be compensated by diffusion. This causes a great dependence on the gas pressure and the best performance can be obtained only within the pressure ranging from 1 to 10 mTorr. This causes a very small flexibility to adjust the manufacturing process and brings a very large limitation to the process of semiconductor manufacturing. When the plasma density is distributed non-uniformly, the etching depth on the wafer or the thickness of the material deposited on the wafer is non-uniform as well,

which will decrease the yield of the device. Especially when the size of wafer increases from 100 mm to 300 mm, the volume of the reaction chamber is enlarged correspondingly and it is very unpractical to reach the uniform plasma density only by means of diffusion.

Additionally, when the diameter of a wafer is 300 mm, the size of the inductively coupled coil needs to be enlarged and the volume of the plasma chamber for processing the wafer is enlarged, which requires that the thickness of the dielectric window 1 has to be increased. Otherwise, the dielectric window 1 cannot bear the pressure difference between the atmospheric pressure outside of the chamber and the vacuum in the chamber. However, the thickened dielectric window 1 will decrease the coupling efficiency of energy because the flux density is not enough to excite the plasma after the RF field penetrates through the dielectric window 1. Furthermore, with the diameter of the wafer increasing, the length of the inductively coupled coil increases significantly to close to or exceed one-eighth wavelength of the RF exciting source. In this way, the transmission line effect of the inductively coupled coil is very obvious and remarkable current and voltage variations will occur, and consequently, the magnetic flux density varies greatly in the plasma and a non-uniform plasma density is produced. As a result the work piece is processed non-uniformly.

On the other hand, when the size of the inductively coupled coil increases, the inductance will increase correspondingly, and accordingly, the voltage at both ends of the inductively coupled coil will increase as well. The large voltage will bring capacitive coupling between the inductively coupled coil and the plasma. Such capacitive coupling increases kinetic energy of the ions. Therefore, it is difficult to control the process precisely. Therefore, the microloading effect of the wafer will be increased and the yield of the device will be decreased. Additionally, particle pollutions will occur on the inner wall of the plasma chamber with the ion collisions of relatively high kinetic energy. Moreover, the large inductance also can cause unstable impedance matching and low coupling efficiency and correspondingly the non-uniformity of radial plasma density increases.

SUMMARY OF THE INVENTION

The purpose of the present invention is to overcome the problem as mentioned

above of the prior art, that is, to provide an inductively coupled coil and an inductively coupled apparatus using the inductively coupled coil. In the inductively coupled coil as the core of the present invention, the coil is constituted by a plurality of respective branches and each respective branch combines a planar segment and a three-dimensional segment organically, such that the plasma is distributed above the wafer in the reaction chamber uniformly and the difference in the speed of chemical reactions on the wafer surface becomes relatively small, and the etching rate is uniform, and accordingly the etching quality of the wafer is improved. The inductively coupled apparatus that applies this inductively coupled coil also has the advantages of uniformly distributed plasma, uniform etching rate, high etching quality etc.

According to one technical solution of the present invention, the present invention provides an inductively coupled coil comprising a plurality of respective branches nested in each other with the same structure, and the plurality of respective branches are coaxial and are arranged symmetrically with respect to an axis.

Wherein, said each respective branch comprises a planar segment and a three-dimensional segment, said three-dimensional segment extends along the axis direction and said planar segment extends all around along a plane that is perpendicular to the axis, and an end at the bottom of said three-dimensional segment is connected to an internal end of the planar segment smoothly.

Wherein, the planar segment of said each respective branch is approximately constructed as concentric circles. Preferably, the planar segment of said each respective branch includes a plurality of bow-shaped patterning portions and at least one connection part which extends and is connected between the patterning portions. Said patterning portions extend along the concentric circles respectively.

Wherein, the length of said each patterning portion ranges from one-fourth circle to a half circle.

Wherein, the three-dimensional segment of said each respective branch rises up spirally along the axis. The diameter of the spiral curve of the three-dimensional segment of said each respective branch is the same, or become small gradually or become large gradually along the direction of rising up.

Wherein, the number of the respective branches is n, wherein n is an integral number being equal to or more than 2.

According to another technical solution of the present invention, the present invention also provides an inductively coupled apparatus which applies the inductively coupled coil as mentioned above, comprising: a reaction chamber and a dielectric window provided on the top of the reaction chamber, an inductively coupled coil is provided on the dielectric window and is connected to a RF source via a RF matcher.

Wherein, the plurality of respective branches of said inductively coupled coil are connected to each other in parallel and then are connected to said RF matcher.

Wherein, each respective branch of said inductively coupled coil is connected to the RF matcher respectively.

Wherein, the respective branches of said inductively coupled coil are connected to each other in parallel, and an input end thereof after parallel connection is connected in series with a variable capacitor and a output end thereof is grounded via a ground capacitor.

Wherein, all input ends of the plurality of respective branches of said inductively coupled coil are each connected in series with a variable capacitor respectively, and then are connected in parallel, and output ends thereof are grounded via a ground capacitor.

From the technical solutions of the present invention as mentioned above, it can be seen that each respective branch of the inductively coupled coil of the present invention comprises a planar segment and a three-dimensional segment, and the three-dimensional segment is located in the middle. For this reason, such a structure makes the electric field strength generated in the middle of the reaction chamber by the inductively coupled coil smaller than the electric field generated at the corresponding place in the reaction chamber by the planar segment of the coil. Thus, the defects of the inductively coupled coil of the prior art can be overcome and accordingly the distribution of plasma at the center and edge of the chamber becomes more uniform.

In addition, because the respective branches with almost the same structure are connected in parallel and symmetrically in the present invention, the inductance of the inductively coupled coil decreases, consequently the plasma with a large area can be

obtained easily and the uniform plasma in the process for a large area can be improved. Meanwhile, such a structure of the inductively coupled coil makes the distribution of the electromagnetic field in the reaction chamber symmetrical and further makes the plasma distribution at the center and at the edge more uniform. The uniform distribution of plasma in the reaction chamber will make the difference in the rate of chemical reactions on the sruface to be etched become relatively small, and the etching rate is uniform .So the etching quality of the wafer is improved.

Besides, the inductively coupled apparatus which applies this inductively coupled coil according to the present invention also has the advantages of uniformly distributed plasma in the reaction chamber, small difference in the speed of chemical reactions on the surface to be etched ,uniform etching rate etc. Therefore, the etching quality of a wafer can be improved using such inductively coupled apparatus for manufacturing process such as etching.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view of a structure of an inductively coupled plasma apparatus of the prior art.

Fig. 2 is a schematic view of a structure of an inductively coupled coil of the prior art.

Fig. 3 is a schematically perspective view of a structure of an inductively coupled coil of the first embodiment of the present invention.

Fig. 4 is a schematically top view of the structure of the inductively coupled coil of the first embodiment of the present invention.

Fig. 5 is a schematically front view of the structure of the inductively coupled coil of the first embodiment of the present invention.

Fig. 6 is a schematically perspective view of a structure of an inductively coupled coil of the second embodiment of the present invention.

Fig. 7 is a schematically front view of the structure of the inductively coupled coil of the second embodiment of the present invention.

Fig. 8 is a schematically top view of the structure of the inductively coupled coil of

the second embodiment of the present invention.

Fig. 9 is a schematically perspective view of a structure of an inductively coupled coil of the third embodiment of the present invention.

Fig. 10 is a schematically front view of the structure of the inductively coupled coil of the third embodiment of the present invention.

Fig. 11 is a schematically top view of the structure of the inductively coupled coil of the third embodiment of the present invention.

Fig. 12 is a schematic view of a structure of an inductively coupled apparatus of the first embodiment of the present invention.

Fig. 13 is a schematic view of the structure of the inductively coupled apparatus of the second embodiment of the present invention.

Fig. 14 is a schematic view of the structure of the inductively coupled apparatus of the third embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The inductively coupled coil of the present invention comprises a plurality of respective branches nested in each other with the same structure. The plurality of respective branches are coaxial and are arranged symmetrically with respect to an axis. The present invention will be explained in detail in connection with the accompanying drawings of Figs. 3 to 11.

As shown in Figs. 3 to 5, the inductively coupled coil of the first embodiment of the present invention comprises two respective branches nested in each other with the same structure. The two respective branches are coaxial and are arranged symmetrically with respect to the axis. Each respective branch comprises a three-dimensional segment 10 and a planar segment 11. The internal end of the planar segment 11 is connected to the end at the bottom of the three-dimensional segment 10 smoothly.

Wherein, the three-dimensional segment 10 extends along the axis direction. Specifically, the three-dimensional segment 10 can rise up spirally along the axis. The diameter of this spiral curve can be the same or different, for example, the diameter may become small gradually or become large gradually along the rising up direction. Moreover,

pitches of the rising up spiral are not limited, and can be an equal distance or an unequal distance, for example, pitches can become large or small gradually.

The planar segment 11 extends all around along the plane that is perpendicular to the axis. Specifically, the planar segment 11 of each respective branch is approximately constructed as concentric circles. The planar segment of said each respective branch includes a plurality of bow-shaped patterning portions and at least one connection part which extends and is connected between the patterning portions. The patterning portions extend along the concentric circles respectively. The so-called patterning portions are the parts which constitute concentric circles in the planar segment 11. In the present embodiment, the length of each patterning portion is about half of a circumference.

As shown in Figs. 6 to 8, the structure of the inductively coupled coil of the second embodiment of the present invention is the same as that of the first embodiment. But the difference between the first and second embodiments is that: the inductively coupled coil of the first embodiment comprises two respective branches nested in each other with the same structure, while the inductively coupled coil of the second embodiment comprises three respective branches nested in each other with the same structure. In the present embodiment, the length of each patterning portion is about one-third of a circumference.

As shown in Figs. 9 to 11, the structure of the inductively coupled coil of the third embodiment of the present invention is the same as that of the first embodiment. But the difference between the first and third embodiments is that: the inductively coupled coil of the first embodiment comprises two respective branches nested in each other with the same structure, while the inductively coupled coil of the third embodiment comprises four respective branches nested in each other with the same structure. In the present embodiment, the length of each patterning portion is about one-fourth of a circumference.

It can be understood that the number of the respective branches included in the inductively coupled coil of the present invention is not limited to two, three or four in the above embodiments. Theoretically, the number can be n, wherein n can be any integral number being equal to or more than 2. As a matter of fact, it will do as long as n meets the relationship as mentioned above and n respective branches of the inductively coupled coil are coaxial and are arranged symmetrically with respect to an axis.

The present invention also provides an inductively coupled apparatus which applies the inductively coupled coil as mentioned above. It will be explained in detail in connection with the accompanying drawings Figs. 12 to 14.

With reference to Figs. 12 to 14, the inductively coupled apparatus of the present invention comprises a reaction chamber 3, a chuck 9 on which a wafer 5 is placed provided in the reaction chamber 3, a dielectric window 1 provided on the top of the reaction chamber 3, a gas inlet 2 located in the middle of the dielectric window 1 and a gas introduction device 8 for introducing the process gas into the reaction chamber 3 through the gas inlet 2. An inductively coupled coil 4 is provided on the dielectric window 1. An input end of the inductively coupled coil 4 is connected to a RF (radio frequency) source 7 via an RF matcher (i.e. a RF matcher) 12. An output end of the inductively coupled coil 4 is grounded via a ground capacitor C0. An inductive electric field generated in the reaction chamber 3 excites the gas that enters into the reaction chamber 3 to produce plasma, to thereby perform process such as etching on the wafer 5.

In the apparatus, the plurality of respective branches of the inductively coupled coil 4 are connected to each other in parallel and the input ends of the plurality of respective branches can be connected in series with a variable capacitor C1. Through changing capacity of variable capacitor C1, the impedance of each respective branch can be changed. The ground capacitor C0 can determine the positions where the maximum and minimum values of the current and the voltage in the coil are, therefore the current and the voltage of each respective branch can be adjusted. Thus, the plasma density distribution can be adjusted through adjusting the current ratio of each respective branch and accordingly the uniformity of the plasma can be controlled further.

As shown in Fig. 12, in the inductively coupled apparatus of the first embodiment of the present invention, the plurality of respective branches of inductively coupled coil 4 are connected to each other in parallel and then are connected to the RF (radio frequency) source 7 via the matcher 12.

As shown in Fig. 13, in the inductively coupled apparatus of the second embodiment of the present invention, the plurality of respective branches of the inductively coupled coil 4 are connected to each other in parallel. And the input ends are

connected in series with the variable capacitor C1 and then are connected to the RF (radio frequency) source 7 via the matcher 12.

As shown in Fig. 14, in the inductively coupled plasma apparatus of the third embodiment of the present invention, the respective branches of inductively coupled coil 4 are each connected in series with variable capacitor C1 at their input ends and then are connected to each other in parallel, and then connected to the RF (radio frequency) source 7 via the matcher 12.

From the above description, it can be seen that each respective branch of the inductively coupled coil of the present invention comprises a planar segment and a three-dimensional segment and the three-dimensional segment is located in the middle. For this reason, such a structure makes the electric field generated in the middle of the reaction chamber by the inductively coupled coil be smaller than the electric field generated at the corresponding place in the reaction chamber by the planar segment of the coil. Thus, the defects of the inductively coupled coil of the prior art can be overcome and accordingly the distribution of plasma at the center and edge of the chamber becomes more uniform.

In addition, because the respective branches with almost the same structure are connected in parallel and symmetrically in the present invention, the inductance of the inductively coupled coil decreases and consequently the plasma with a large area can be obtained easily and the uniformity of the plasma in the process for a large area can be improved. Meanwhile, such a structure of the inductively coupled coil can make the distribution of electromagnetic field in the reaction chamber symmetrical and further make the plasma distribution at the center and the edge more uniform. The uniform distribution of plasma in the reaction chamber will make the difference in the speed of chemical reactions on the surface to be etched become relatively small, and the etching rate is uniform and accordingly the etching quality of the wafer is improved.

It can be understood that the inductively coupled apparatus which applies this inductively coupled coil according to the present invention also has the advantages of uniformly distributed plasma in the reaction chamber, small difference in the speed of chemical reactions on the surface to be etched, uniform etching rate etc. Therefore, the

etching quality of the wafer can be improved using such inductively coupled apparatus for manufacturing process such as etching.

It is to be indicated that the number of RF (radio frequency) sources used in the present invention can be one or more. Moreover, the plurality of respective branches may be connected to the RF (radio frequency) source 7 via the matcher 12 respectively.

It is to be further indicated that the inductively coupled coil and the inductively coupled apparatus employing the inductively coupled coil are mainly applied to the semiconductor wafer processing equipments, but not limited to that, and can be applied to other equipments.

The foregoing description is only the detailed implementations of the invention. But the scope of the invention is not limited to the disclosure of the preferred embodiment. The modifications and equivalents to those embodiments that may be obtained easily by one skilled in the art without departing from the scope of the present invention are intended to be included within the scope as defined in the present invention.

Claims

1. An inductively coupled coil, comprising a plurality of respective branches nested in each other with the same structure, and the plurality of respective branches are coaxial and are arranged symmetrically with respect to an axis.

2. The inductively coupled coil according to claim 1, wherein said each respective branch comprises a three-dimensional segment and a planar segment, said three-dimensional segment extends along the axis direction and said planar segment extends all around along a plane that is perpendicular to the axis, and an end at the bottom of said three-dimensional segment is connected to an internal end of the planar segment smoothly.

3. The inductively coupled coil according to claim 2, wherein the planar segment of said each respective branch is approximately constructed as concentric circles.

4. The inductively coupled coil according to claim 3, wherein the planar segment of said each respective branch includes a plurality of bow-shaped patterning portions and at least one connection part which extends and is connected between the patterning portions, and said patterning portions extend along the concentric circles respectively.

5. The inductively coupled coil accroding to claim 4, wherein the length of said each patterning portion ranges from one-fourth circle to a half circle.

6. The inductively coupled coil according to any one of claims 1 to 5, wherein the three-dimensional segment of said each respective branch rises up spirally along the axis.

7. The inductively coupled coil according to claim 6, wherein the diameter of the spiral curve of the three-dimensional segment of said each respective branch is the same, or becomes small gradually or becomes large gradually along the rising up direction.

8. The inductively coupled coil according to any one of claims 1 to 5 and claim 7, wherein the number of the respective branches is n, wherein n is an integral number being equal to or more than 2.

9. The inductively coupled coil according to claim 6, wherein the number of the respective branches is n, wherein n is an integral number being equal to or more than 2.

10. An inductively coupled apparatus which applies the inductively coupled coil according to any one of claims 1 to 9, comprising a reaction chamber and a dielectric window provided on the top of the reaction chamber, characterized in that the inductively coupled coil is provided on the dielectric window and is connected to a RF source via said RF matcher.

11. The inductively coupled apparatus according to claim 10, wherein the plurality of respective branches of said inductively coupled coil are connected to each other in parallel and then are connected to a RF matcher.

12. The inductively coupled apparatus according to claim 10, wherein each respective branch of said inductively coupled coil is connected to said RF matcher respectively.

13. The inductively coupled apparatus according to any one of claims 10 to 12, wherein the respective branches of said inductively coupled coil are connected to each other in parallel, the input end thereof after parallel connection is connected in series with a variable capacitor and the output end thereof is grounded via a ground capacitor.

14. The inductively coupled apparatus according to any one of claims 10 to 12, wherein input ends of respective branches of said inductively coupled coil are each connected in series with a variable capacitor respectively and then are connected in parallel, and output ends thereof are gounded via an ground capacitor.