An apparatus for etching and for stripping resist from a semiconductor wafer has a microwave source for creating a plasma from which a gas with a high concentration of free radicals is discharged, and an RF source for creating a plasma of the discharged gas to produce high ashing rates. The wafer is positioned over a hotplate and can be moved during an etching or stripping method over a range of processing positions. Moving the wafer allows control of the energy; control of the anisotropy of walls formed during etching; processing with or without heating the wafer; alternating high and low temperature processing; and etching or stripping resist on two sides of a wafer simultaneously.
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METHOD AND APPARATUS FOR SEMICONDUCTOR ETCHING AND STRIPPING

Field of the Invention

This invention relates to a method and apparatus for processing semiconductor wafers, and particularly to a method and apparatus for etching layers on a wafer and for stripping resist.

Background of the Invention

When processing a semiconductor wafer, it is often desirable to form a layer of a material in a desired pattern. To form the desired pattern, the layer is deposited on a surface of the wafer and then is covered in the desired pattern with a resist, i.e., a material that is resistant to an etchant to be used. The wafer is then exposed to an etchant which etches away parts of the layer not covered with resist, thus leaving the layer in the desired pattern. After the resist has served its purpose, it is stripped (removed) from the surface of the wafer.

An apparatus that can be used for both etching layers and stripping resist is described in commonly assigned U.S. Patent No. 5,228,052, the teachings of which are incorporated herein by reference. The apparatus described in that patent has a chamber in which a wafer is treated. In the chamber, the wafer is supported over a horizontal hotplate with a lifting apparatus that has pins that extend upwardly through openings in the hotplate. The lifting apparatus raises and lowers the wafer from a position in which the wafer is on the hotplate, to a position in which the wafer is elevated 1mm over the hotplate. The wafer can be raised to a still higher position over the hotplate when the wafer is inserted into or removed from the chamber, but the apparatus is designed so that no processing can be performed at this position.
An inlet pipe extends into the chamber and carries a process gas, typically including at least oxygen gas ($O_2$) and a forming gas such as $N_2H_2$. The process gas may, but does not necessarily, also include $CF_4$. If the gas for an etching process includes $CF_4$, the gas has a low concentration of oxygen and a high concentration of $CF_4$ to create mainly fluorine radicals or ions; for a stripping process, the gas has a high concentration of oxygen and low concentration of $CF_4$ to create mainly oxygen radicals or ions. These processes can be performed with $O_2$ and $N_2H_2$ and without $CF_4$, in which case the heat from the hotplate provides additional energy.

The apparatus uses the process gas to etch or strip in one of two different ways: (1) a reactive ion etching (RIE) process in which the gas is ionized over the wafer; or (2) a radical process in which radicals of the gas are discharged from a microwave plasma at the inlet tube. These processes etch the layer or ash the resist. The rate of etching or stripping is known as the ashing rate, a parameter that is typically measured in angstroms per minute.

According to the RIE process, a radio frequency (RF) voltage source creates a plasma that causes oxygen or fluorine ions to form over the wafer. The RF source is coupled to a top electrode positioned over the wafer, and to the hotplate, which serves as the bottom electrode. As described in the incorporated patent, these top and bottom electrodes serve as a double cathode to accelerate the production of ions. These ions are drawn to the wafer to etch a layer or to strip resist.

According to the radical process, a microwave source coupled to the inlet pipe is activated to create a microwave plasma that causes oxygen or fluorine radicals to be discharged from the plasma into the treatment chamber. These radicals react with the resist or other layer to decompose it into other gases, which are then exhausted through an exhaust pipe coupled to a vacuum pump. The
vacuum pump also keeps the pressure in the chamber low, typically about 50-500 mT (milli-Torr). Depending on the process gas that is used, this process may or may not need added heat from the hotplate.

These two processes can be performed alternatively or sequentially, but an interlock between the RF source and the microwave source allows only one of the two processes to operate at one time. If they are performed sequentially for stripping, the RIE process is generally performed first. The wafer is at the elevated position over the hotplate and a process gas is introduced through the inlet pipe. The RF plasma formed over the wafer creates ions that have energy for etching or stripping. This RIE process is particularly useful for stripping hardened parts of the resist.

After the RF plasma has been used, the RF source is turned off. If CF₄ is not used, the wafer is lowered onto the heated hotplate to provide additional energy; if CF₄ is used, the wafer can be kept at the 1mm elevated position. For this discussion, it is assumed that CF₄ is used. The process gas is introduced and a microwave source creates a plasma in the inlet pipe. This plasma causes oxygen and fluorine radicals to be discharged downstream from the microwave source. The resist, which is typically made of CₓHᵧNᵦ, reacts with the fluorine radicals to create HF. This reaction gives off energy which assists the oxygen radicals in decomposing the resist into CO₂, NO₂, and H₂O. The fluorine thus serves as a catalyst. The gases produced by this decomposition are drawn out of the chamber through the exhaust tube.

During an etching process with radicals only, the etching is isotropic, i.e., etching occurs in all directions at the same rate. It is often desirable, however, to produce a wall slope that is anisotropic, i.e., in which the wafer is etched more in the depth direction than along a lateral direction in order to produce steeply sloped walls. Such anisotropy can be achieved in anisotropic etching
systems which control the slope of the etched walls by using very low pressure (about 1-10 mT), and highly corrosive etchants. Because of the highly corrosive etchants, a typical anisotropic etching system has corrosion resistant components that make the etcher expensive and not economical for processes that do not require a high degree of anisotropy. Some anisotropy can be achieved with the apparatus described above using an RIE plasma process, but the user has little control over the degree of anisotropy because the RIE process can only be performed at the position that is 1mm over the hotplate.

It is an object of the present invention to provide a method and apparatus for improving the rate of etching and stripping.

It is another object of the present invention to provide a method and apparatus allowing a user greater flexibility in processing wafers.

Summary of the Invention

According to the present invention, a microwave plasma is activated to discharge a gas with free radicals; at the same time, an RF plasma is generated over the wafer to ionize the free radicals produced by the microwave plasma. By combining these processes to create ionized radicals, the plasma can ash the resist or layer at an ashing rate that is much higher than either of the processes individually.

The present invention also includes a lifting mechanism that has a motor, operated by a controller, for setting the wafer on at one of a number of different processing positions typically expressed in terms of elevation over a hotplate. The controller is programmable so that the different positions can be set and later modified if desired. The ability to process at various processing positions provides users with increased processing flexibility, including an ability to vary the processing temperature in or between steps, and an ability to control
the electric field of ions to etch with different levels of anisotropy. These different processing positions can be used with the combined process noted above to quickly ash resist or other layer.

Other objects, features, and advantages will be apparent from the following detailed description, the drawings, and the claims.

**Brief Description of the Drawings**

Fig. 1 is a pictorial and block representation of an apparatus for etching and stripping according to the present invention.

Fig. 2(a) and 2(b) are cross-sectional views of a wafer, illustrating isotropic and anisotropic etching, respectively.

Fig. 3 is a graph illustrating an electric field versus a distance over a hotplate.

Fig. 4 is a graph illustrating the temperature of a wafer versus time at a specified distance over a hotplate and under a specified pressure.

**Detailed Description**

Referring to Fig. 1, a semiconductor wafer 10 to be processed is positioned over a horizontally disposed hotplate 12 in an enclosed treatment chamber 16. Wafer 10, which is typically flat and circular with a diameter of four to eight inches, rests horizontally on support pins 18 that extend through openings in hotplate 12 along its thickness direction. Wafer 10 and hotplate 12 thus lie in parallel horizontal planes.

A process gas is introduced into chamber 16 from a gas source 20 through an inlet pipe 21. A microwave source 22 at inlet pipe 21 causes a microwave plasma 24 to be formed at the inlet pipe, thus discharging a reactive gas 26 with a high concentration of active free radicals. Gas 26 passes through openings (not shown) in a top electrode 28 that is
mounted above the wafer and is configured as in the incorporated patent. Under appropriate conditions, these active free radicals can thus decompose and evaporate a resist film on wafer 10 by converting the resist to gases. A vacuum 32 draws away these gases through an exhaust tube 34, and also maintains pressure on the order of 50-500 mT in the chamber.

An RF source 30 is electrically coupled to top electrode 28 and to hotplate 12, which thus serves as a bottom electrode. Electrodes 28, 12 thus form a double cathode. Source 30 provides an RF voltage that causes an RF plasma 32 to form over wafer 10. RF plasma 32 creates reactive ions that ash the resist from wafer 10.

A transparent cover 48 and an end point detector 50 are used to detect when ashing caused by the RF plasma begins and ends. End point detector 50 has a filter and an optical detector for detecting photons that are released in the RF plasma when OH radicals are excited to become water.

According to the present invention, a gas is introduced from gas source 20 and microwave source 22 is activated to produce reactive gas 26 having a high concentration of free radicals discharged from the microwave plasma. An RF plasma is generated in the microwave-generated reactive gas 26 to ionize its free radicals. If, for example, a process gas from gas source 20 includes CF₄ and oxygen, the discharged gas from the microwave plasma has a high concentration of fluorine and oxygen radicals, respectively, in the gas over the wafer. If an RF plasma is then initiated in this discharge gas, the resulting ions that are produced are different from those in either the microwave discharge gas itself or from an RF plasma of CF₄ and oxygen gas without the microwave discharge. This different plasma has been found to substantially increase ashing during either etching or stripping.

In an experiment, a wafer covered with a resist was raised to an elevated position over a hotplate. The process
gas that was introduced included a generally known combination of oxygen, $\text{CF}_4$, and $\text{H}_2\text{N}_2$. Using only microwave-generated radicals, an ashing rate was found to be 18,000 A/min (angstroms per minute); using only an RIE process with RF plasma, an ashing rate was found to be 14,000 A/min. When these two processes operated simultaneously as described above, however, an ashing rate of 58,000 A/min was measured. Experience had shown that ashing rates of this magnitude were not achievable in an apparatus of this type with either of the processes, regardless of the temperature of the hotplate or the power levels of either plasma. Such ashing rates were only obtained in the combined processing when a plasma was initiated in a gas mixture that was already highly seasoned with very reactive free radicals discharged from the microwave plasma.

By combining these two processes in a single chamber and improving the ashing rate, the total time for ashing is reduced. In another experiment, a heavily ion-implanted photoresist cross-linked with UV treatment was put on the hotplate for etching. It was found that when etching with the combined radical and RIE process, the total processing time was reduced 30% compared to the two-step RIE process followed by the radical process.

Such a reduction in ashing time is important because heat, fluorine, and electric fields produced with an RF plasma can all risks damaging electrical components being manufactured. By reducing the time for ashing, these risks can be reduced. Furthermore, the throughput can be increased and thus the cost of production can be reduced significantly.

The apparatus of the present invention further includes a mechanism 40 that can variably adjust the position of wafer 10 relative to the hotplate and top electrode 28. These positions are typically expressed as a number of different processing heights over hotplate 12. The mechanism has a motor 42 that uses gears (not shown) to
vertically move a rod 41 that is coupled to pins 18 through a platform 43. This mechanism is controlled with a controller 14 that is used to define and preset elevational positions over the hotplate. These preset positions can further be revised by a user with the controller to define new preset heights. In one embodiment, the wafer can be set on the hotplate itself and at positions of 1mm, 2mm, 3mm, 5mm, 7mm, and 13mm over the hotplate. Processing can be performed at each of these positions. This ability to set different processing positions allows users greater flexibility in processing in a number of ways.

The adjustable pin height allows flexible control of the slope of the walls of an etched layer. Referring to Figs. 2(a)-2(b), an example of isotropic etching is shown in Fig. 2(a). A wafer has a layer 60 to be patterned formed over a substrate 62, and a resist 64 formed over layer 60. The resist has an opening 66 through which an etchant is provided. As indicated, because etching occurs in all directions, by the time the thickness of layer 60 is etched, overhangs 68 are formed.

The apparatus of the present invention allows all of the significant parameters that control etching to be independently controlled. The number of active free radicals in the gas mixture is controlled by the microwave source and the resulting downstream discharge; the percentage of ions within the plasma is controlled by the power level of the RF plasma; and, most significantly, the energy of the ions is controlled by the location of the wafer over the hotplate within the plasma, thus controlling the electric field of the ions.

Referring to Fig. 2(b), when the apparatus is used for etching and the RF plasma is activated, high slopes in the side walls can be achieved by controlling the electric field that directs ions onto the wafer surface. The energy of these ions and the percentage of ions in the reactive gas mixture determine the degree of anisotropy of side walls 70
in layer 72 due to the etching process. Side walls with slopes of 70°-80° have been achieved with such a system.

When the wafer is placed on the hotplate surface the ion energy is the highest; when the wafer is elevated above the hotplate, the ion energy decreases. This relationship of the elevation of the wafer over the hotplate versus ion energy is illustrated in the curve in Fig. 3. In this figure, a sputtering rate of silicon dioxide from a surface of a wafer is shown as a function of the elevation of the wafer over the hotplate. The sputtering rate, a direct measure of the ion-bombardment energy, rapidly falls off as the wafer is elevated. This relationship, however, incorporates conflicting priorities. While heat and high energy can damage electrical components, they also help accelerate the ashing process, thus reducing the time and some of the risk of damage.

By using the microwave and RF sources together and by adjusting the wafer elevation with the pin lifting mechanism, the etching can be controlled to provide a desired degree of anisotropy. Moreover, the elevation of the wafer, and thus the electric field, can be altered during a processing step or between a sequence of processing steps to tailor the walls to a desired configuration.

The ability to adjust the elevation of the wafer over a range of positions also provides users with greater flexibility in controlling the temperature of the wafer. Such control can be significant because higher temperature creates a greater risk of electrical damage to circuitry being formed on the wafer. Because of the low pressure in the chamber, heat is generally transferred from the hotplate by radiation without significant heat transfer from conduction or convection. Consequently, the proximity of the wafer and the hotplate is very important in determining the temperature.

By maintaining the wafer at an elevated position above the hotplate, ashing can be performed with an RIE process at
a relatively cool temperature. With the hotplate at 260°C, the temperature of the wafer remains low for a period of time. Fig. 4 illustrates a graph of temperature versus time for an 8-inch wafer elevated 1 mm above the hotplate at 260°C with a chamber at a pressure of 100 mT. As indicated in Fig. 4, the temperature remains for over 60 seconds below 120°C, which is considered a very low temperature in typical semiconductor wafer processing.

The temperature can therefore be varied by moving the wafer among different positions. To change processing from a low to a high temperature after a desired amount of resist has been stripped, the wafer is lowered near or onto the hotplate so that the temperature of the wafer rises rapidly. This process of etching at a higher level and lowering the wafer is particularly useful for stripping heavily ion-implanted photoresists for which it may be desirable to ash away a top surface at a lower temperature before the wafer is heated.

Alternatively, it can be desirable to use as a first process an RIE process at a lower position so that the ions ash away hardened resist. Next, for a second process, the wafer is elevated to increase distance from the hotplate and is used with a combined radical/RIE process to obtain a high ashing rate for a short period of time, e.g., ten seconds.

It is generally difficult to quickly cool a wafer that has been heated on a hotplate, because the low pressure in the chamber causes heat to be conducted away from the wafer very slowly. To advance the cooling of the wafer, the wafer is raised over the hotplate and a burst of helium is introduced into the chamber for about 15 seconds. The helium conducts the heat from the wafer, thus providing a quick reduction in heat, e.g., from 260°C to 180°C.

The ability to process at relatively high distances from the hotplate (e.g., 5 mm or more, as compared to 1 mm) also provides flexibility in processing the rear side of the wafer. At the higher elevated positions above the hotplate,
it is easier to process the front and rear of the wafer at the same time. Such double sided processing can be used for both etching and stripping. At positions when the wafer is very close to the top electrode, processing can be performed primarily to the rear side of the wafer.

Having described embodiments of the present invention, it should be apparent that modifications can be made without departing from the scope of the appended claims. For example, while certain gases are recited, other gases can be used for etching or for removing resist. In the above discussion, the bottom electrode is also a hotplate, but the hotplate can be omitted if some other source of heat, such as an ion lamp, is used. Thus, the bottom electrode need not also be a hotplate.

What is claimed is:
Claims

1. A method for processing a semiconductor wafer having a layer of material and a resist formed over said layer, the method comprising the steps of:

   (a) generating a microwave discharge gas with a microwave source, said discharge gas having a number of free radicals;

   (b) providing said microwave discharge gas over said semiconductor wafer; and

   (c) generating a plasma of said microwave discharge gas over said semiconductor wafer to form ions to ash one of said resist and said layer from said semiconductor wafer.

2. The method of claim 1, wherein said plasma is generated with at least one electrode, the method further including, during step (c), a step of varying a distance between said electrode and said semiconductor wafer to alter the electric field acting on the ions.

3. The method of claim 1, wherein said plasma is generated with at least one electrode, the method including, prior to step (a), a step of setting said semiconductor wafer at one of a plurality of locations relative to the electrode to obtain a desired degree of anisotropy in etching.

4. The method of claim 3, further including steps of moving the semiconductor wafer to another of the plurality of locations relative and repeating steps (a)-(c).

5. The method of claim 1, wherein step (a) includes generating said microwave discharge gas with oxygen radicals.
6. The method of claim 1, wherein step (a) includes generating said microwave discharge gas with fluorine radicals.

7. An apparatus for processing a semiconductor wafer having a layer and a resist formed thereon, the apparatus comprising:
   a treatment chamber;
   means for supporting the semiconductor wafer in said treatment chamber;
   first means for generating a discharge gas with a number of free radicals and for providing said discharge gas in said treatment chamber; and
   second means for generating a plasma of said discharge gas over the semiconductor wafer to ionize said number of free radicals to ash one of said layer and said resist from the semiconductor wafer, said first and second means for generating being operable simultaneously.

8. The apparatus of claim 7, wherein said second means includes a generally horizontal electrode, the supporting means supporting the wafer horizontally, the apparatus further comprising means for moving the semiconductor wafer among a plurality of positions spaced from said electrode.

9. The apparatus of claim 8, wherein the moving means is controllable so that said plurality of positions can be set with defined values and redefined with new values.

10. The apparatus of claim 8, wherein said plurality of positions range from at least 1mm to at least about 7mm spaced over said electrode.

11. An apparatus for processing a semiconductor wafer, the apparatus comprising:
a treatment chamber;
a conduit for providing a gas into said treatment chamber;
means for forming over said wafer a plasma of said gas,
said forming means including a horizontal electrode in said treatment chamber; and
a wafer support mechanism for supporting the wafer and for raising the wafer from a first position on said horizontal electrode to one of a plurality of positions over said horizontal electrode at which processing can be performed.

12. The apparatus of claim 11, wherein said wafer support mechanism has pins extending through said electrode.

13. The apparatus of claim 11, wherein said electrode is also a hotplate.

14. The apparatus of claim 11, wherein said wafer support mechanism includes a motor and a controller.

15. The apparatus of claim 14, wherein said controller is coupled to said motor to variably define said plurality of positions.
FIG. 4

HEAT UP DURING RIE MODE