

Method and Device for Plasma Treatment of Substrates

Specification

This invention relates to a device for bombarding a substrate with a plasma as well as a corresponding method.

Many semiconductor production processes contain one or more plasma treatment steps. The plasma can be used, e.g., for coating a substrate, for depositing semiconductor layers, for etching a substrate, for plasma activation, or for creating an ion reservoir. In this case, gases such as, e.g., silane (SiH_4), helium (He), argon (Ar), hydrogen (H_2) and/or nitrogen trifluoride (NF_3) are directed into the plasma chamber. SiH_4 or H_2 are used, e.g., in the deposition of semiconductor layers, and NF_3 is used in the plasma etching of semiconductor layers. If a mixture made of noble gas and a reactive gas is used, the layer composition can be controlled by the adjustment of the gas mixture ratios. Thus, not only metals, but also oxides, nitrides and carbides can be deposited. Working gas and/or selection of gas mixture, gas flow and pressure has/have an influence on the plasma that is produced. Atmospheric-pressure plasma, low-pressure plasma or high-pressure plasma are practical examples. In contrast to low-pressure plasma or high-pressure plasma, atmospheric-pressure plasmas do not require any reaction vessel, which ensures the maintenance of a pressure level that is other than atmospheric pressure or deviating gas atmospheres. Plasma chambers can be operated in a pulsed manner or continuously, for example with plasma processes based on high-frequency discharge, microwave

electrostatic holding is a good alternative. The substrate can be secured by an electrical voltage between the sample-holder electrodes. Electrostatic wafer-holding devices are part of the plasma chamber and are used as lower electrodes to generate plasma. In this case, the electrode is electrically insulated by the chamber wall. In embodiments where an inner round electrode and several outer ring electrodes are used, the individual ring electrodes are mutually insulated from one another. Electrostatic wafer-holding devices are shown in, for example, US 2002/0159216 A1 as well as EP 0473930 A1.

Wafer-holding devices have to pick up and put down a wafer on the holding device or lift away a wafer that has been put down from the holding device in the holding device of a lifting mechanism with loading pins. A lifting mechanism is integrated in a part of the second electrode in WO 03/038891 A1 or is integrated in the substrate holder in US 2012/0003836 A1 and can be operated by means of a control network.

Structures with loading pins as sample pickup devices have the following problem: because of the loading pin, there is inhomogeneity of the plasma field, which leads to voltage peaks during the process at the necessary recesses.

Embodiments of this invention provide a method and a device that ensure the generation of homogeneous plasma with a uniform profile, in particular over the entire substrate surface.

According to a first aspect of the present invention, there is provided a device for bombarding at least one substrate with a plasma with a first electrode and a second electrode that can be arranged opposite thereto, which electrodes are formed together producing the

plasma between the electrodes, characterized in that at least one of the electrodes is formed from at least an inner and an outer electrode unit, wherein the electrode units are on the same potential, wherein the inner electrode unit can be driven upwards and a robot arm can place the substrate on the inner electrode unit.

According to a second aspect of the present invention, there is provided a method for bombarding at least one substrate with a plasma produced by a first electrode and a second electrode arranged opposite to the first electrode, wherein at least one of the electrodes has at least an inner and an outer electrode unit, wherein the inner electrode unit is driven upwards and a robot arm places the substrate on the inner electrode unit.

All combinations of at least two features indicated in the specification, the claims and/or the figures also fall within the scope of the invention. In the indicated ranges of values, values that lie within the

above-mentioned limits are also to be considered disclosed as boundary values and can be claimed in any combination.

The basic idea of embodiments of this invention is to design at least one of the two opposing electrodes, in particular the lower one in the plasma chamber and/or the two-part one used for picking up substrate or the one made of two electrode units.

In other words, embodiments of the invention relate to a unit and a method for generating an optimum field homogeneity with a two-part electrode for plasma chambers. An in particular circular substrate receptacle is integrated into the lower electrode, whereby the lower electrode has an outer periphery (outer electrode unit) and an inner area (inner electrode unit). The inner electrode is preferably movable relative to the outer electrode and is used at the same time to hold substrates in the plasma chamber.

According to a preferred embodiment of the indicated invention:

- 1) The inner electrode of the sample pick-up and removal (wafer-holding device) is used,
- 2) Loading and unloading are without loading pins, and
- 3) After the loading, the inner electrode unit runs into a corresponding recess of the outer electrode unit, whereby in particular a closed, flat and/or contact-providing surface, in particular with a uniform potential, is produced.

The movable inner electrode unit replaces in particular the loading pins for loading and unloading the substrates, so that the latter can be eliminated according to embodiments of the invention. This design makes possible a more homogeneous plasma in comparison to structures with loading pins as a sample pickup device. Because of the loading pins, an

inhomogeneity of the plasma field results, which leads to voltage peaks during the process at the corresponding recesses.

Because of a full-surface contact surface of the inner and outer electrode unit that can be produced according to embodiments of the invention with a lateral surface of the substrate, these field shifts do not occur, and a more homogeneous plasma is produced.

In addition, the time-consuming adjustment of the loading pins is eliminated, which in the outer electrode unit is replaced by the mechanical construction of the inner electrode unit and leads to a smaller amount of time spent in comparison to the conventional designs.

Another advantage comes from the large-area seating in the handling of thin substrates, which cannot be handled with the loading pin design because of their bending. The size of the inner electrode unit is adaptable and thus suitable for different types of substrates.

Embodiments of the invention accordingly relate in particular to a two-part electrode for plasma chambers with optimal electrical field homogeneity. In a first embodiment of the invention, the plasma chamber has an RF electrode (second, in particular upper, electrode) and a counter-electrode (first, in particular two-part, electrode) with a substrate holder for picking up a substrate. In particular, a high-frequency alternating field for producing plasma is generated between the RF electrode and the counter-electrode. In a second, preferred embodiment, the plasma chamber has in particular an RF electrode (second, in particular upper, electrode) and an RF counter-electrode (first, in particular two-part, electrode) with a substrate holder for picking up a substrate. The housing is the counter-pole in this embodiment. Preferably, the housing is grounded.

A substrate, preferably a wafer, is positioned between the first and the second electrodes. The first and second electrodes are arranged on opposite sides of the plasma chamber and are preferably referred to as lower and upper electrodes. In the embodiment of the invention, one of the two electrodes, preferably the lower electrode, consists of two assemblies, in particular an inner electrode unit and an outer electrode unit.

The inner electrode unit is used in the substrate pickup and substrate removal for the substrates that are to be treated (wafers, thin-layer substrates, etc.).

The substrate holder (first electrode) is constructed in particular in such a way that in the loading of the first electrode with the substrate, the inner electrode unit (designed in particular as a sample holder) is run upward, and a robotic arm can put into position the substrate on the inner electrode unit. The robotic arm (paddle) has in particular a corresponding recess for picking up the substrate.

The inner electrode unit is moved in particular in a Z-direction, preferably between 0 and 50 mm upward, more preferably between 2 and 25 mm, and most preferably between 2 and 10 mm upward. The zero point in the Z-direction is the plasma application point, where the support surfaces of the inner and outer electrode units are aligned at the same height, i.e., form a support plane E that is in particular completely closed and that preferably has a constant potential.

The substrate holder is preferably built so that after the loading, the inner electrode runs into the part of the outer electrode, whereby a closed, flat, and/or contact-providing surface, in particular with a uniform potential, is formed.

The electrode unit is preferably designed as a sample holder/substrate holder. The substrate holder and/or the sample holder can have attaching elements for attaching the substrates. The attaching elements can be mechanical clamps and/or adhesive, in particular switchable, surfaces and/or vacuum strips, and/or electrodes as part of an electrostatic device and/or magnetic devices, in particular permanent magnets or electromagnets. If substrate holders and sample holders have attaching elements, the attaching elements can be switched independently of one another. As a result, it is made possible according to embodiments of the invention to detach a substrate from the substrate holder, while the centrically-mounted inner sample holder can move and in this case maintains the attachment of the substrate at the same time.

During the unloading process, the inner electrode unit is accordingly raised so that after the plasma treatment, the substrate can be removed with the automatic robotic gripper.

As a substrate, in particular a product substrate, preferably a semiconductor wafer, is used according to embodiments of the invention. The substrates can have any shape but are preferably circular. The diameters of the semiconductor substrates preferably correspond to the diameters of 2 inches, 4 inches, 6 inches, 8 inches, 12 inches or 18 inches that are standard in the semiconductor industry, but they can also deviate from the latter if necessary. Substrates preferably consist of materials and/or alloys such as, e.g., silicon (Si), silicon oxide (SiO_2), silicon nitride (Si_3N_4), aluminum (Al), tungsten (W) and titanium (Ti). In principle, the embodiment of the invention can handle any substrate, in particular independently of its diameter.

Another embodiment of the invention consists in particular in that the inner electrode unit is used at the same time as a substrate receptacle and is movable, and thus a simple loading and unloading of the sample without loading pins is made possible. The substrate receptacle is used to pick up a large-area substrate or substrate stack, or a number of electronic component groups, in particular wafers.

Another embodiment of the invention consists in arranging or aligning the support surfaces of the inner and outer electrodes at the same height and thus in forming a homogeneous first electrode at the plasma application point. The substrate lies in particular over the entire surface on the inner and the outer electrode units and is held by the action of gravity and by a focus ring on the first, in particular lower, electrode. Another or an additional possibility of attaching substrates to the sample holder is done using vacuum or underpressure. Because of a full-surface contact surface of the inner and outer electrodes, field shifts do not occur, and a more homogeneous plasma is produced.

The second electrode that is designed in particular as a plasma electrode has in particular a carrier part or an outside part made of materials such as ceramic, glass, silicon, or a mineral-ceramic composite material, as well as an electrode head made of a conductive material.

The first, in particular two-part, electrode preferably consists of materials and/or alloys that consist of wolfram (W), copper (Cu), aluminum (Al), platinum (Pt), chromium (Cr), nickel (Ni), gold (Au), titanium (Ti), and/or high-grade steel.

Other components of the device preferably consist of graphite or silicon carbide. If necessary, different carrier materials and/or electrode materials are used, since the

controllable, in this connection, second generator for the second electrode. By the selection of external electrical parameters such as voltage, current and frequency, the plasma discharge can be controlled depending on need and application. Thus, it is possible, by individually-matched operating conditions, to increase the selectivity of plasma-chemical processes.

The in particular dielectric focus ring preferably consists of the same material as the substrate. Preferred dielectric materials are silicon dioxide (SiO_2), silicon nitride (Si_3N_4), aluminum oxide (Al_2O_3), silicon carbide (SiC) and silicon carbonitride (SiCN). The focus ring is applied in particular on the top of the outer electrodes, i.e., on the support plane. Selection of material and positioning on the first electrode are to be selected according to embodiments of the invention in such a way that potential differences that are as small as possible or no potential differences occur between the focus ring and the substrate. In this connection, the homogeneity at the edge of the substrate is influenced in a positive manner.

The embodiment of the invention is preferably found in a hermetically-sealable chamber that is accessible, in particular evacuable, by raising a cover, most preferably in a plasma chamber. In addition to high-grade steel chambers, quartz glass chambers can be used.

The plasma chamber is evacuated for plasma bombardment in particular at a pressure of less than 1 bar, preferably less than 1 mbar, more preferably less than 0.1 mbar, most preferably at less than 0.01 mbar, and with utmost preference less than 0.0001 mbar. The plasma chamber can also preferably be subjected to overpressure. In this case, the maximum pressure is in particular greater than 1 bar, preferably greater than 1.5 bar,

more preferably greater than 2 bar, most preferably greater than 5 bar, and with utmost preference greater than 10 bar.

An ion stream measuring sensor can be integrated into the plasma chamber for process control. The two-part electrode can be used for different types of operation of the plasma chamber, such as, e.g., PE (plasma-etching) operation or RIE (reactive-ion-etching) operation. In semiconductor technology, an RIE operation is used to produce structures in wafers since the directed plasma strikes the substrate in a perpendicular manner.

Depending on the plasma gas that is used and the energy that is supplied, temperatures of 400 to 50,000 K are reached in the plasma jet. Based on the processes in the plasma chamber, a considerable increase in temperature can occur, which leads to a heating of the substrate. The cooling or heating of the substrate is done via a thermal coupling to the substrate receptacle, which has in particular cooling and/or heating elements. In order to ensure a uniform thermal coupling between substrate and substrate receptacle, an adequate thermal contact of the substrate with the substrate receptacle (first electrode) according to embodiments of the invention that is over the entire surface can be produced during the plasma treatment. A coolant, e.g., liquid helium, can be circulated on the bottom of the wafer in order to cool the wafer. Instead of a cooling line, other cooling elements can also be provided, such as, e.g., a Peltier element. The substrate can be heated in particular by a heating system, which is arranged in an integrated manner in particular in the first, two-part electrode.

In the case of temperature-dependent reactions, the plasma is used in particular for the etching of a substrate. In this connection, it is important to maintain a