APPARATUSES AND METHODS FOR CLEANING A SUBSTRATE

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BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to semiconductor manufacturing and, more particularly, to apparatuses and methods for use in processing a substrate.

2. Description of the Related Art

In the fabrication of semiconductor devices, there is a need to perform substrate (*e.g.*, semiconductor wafer) cleaning. For example, the process of manufacturing electronic devices on semiconductor wafers involves a complex process of depositing and removing a number of layers. Typically, patterning of layer materials includes the application of an organic photoresist onto the semiconductor wafer. After plasma chemistry etches a target material, the semiconductor wafer needs to be cleaned to remove the organic photoresist. If the organic photoresist is not removed, the organic photoresist will contaminate the semiconductor wafer resulting in damage to the electronic devices on the semiconductor wafer. In addition, after a chemical mechanical polishing (CMP) operation, residual particles or films are left on the surface of the semiconductor wafer. Similarly, these residual particles or films may cause defects such as scratches on the wafer surface which may cause devices on the wafer to become inoperable. To avoid damaging the devices, the wafer also needs to be cleaned after the CMP operation. As such, cleaning operations define a very critical step that is repeated many times throughout the process of fabricating semiconductor devices.

Figure 1 is a simplified side view of a conventional system used to clean semiconductor wafers. The cleaning system includes two brushes 110 configured to receive semiconductor wafer 112 between the brushes. Foam 114 is supplied to the surface of semiconductor wafer 112 and brushes 110 rotate to scrub the surface of the semiconductor wafer to remove particles and film. The problem with applying foam 114 in an open environment is that the foam haphazardly grows around brushes 110 and cannot be directed to a particular surface area of

semiconductor wafer 112. In other words, the flow of foam 114 is difficult to control when applied in an open environment. Furthermore, different properties of foam 114 result in different cleaning capabilities, and the properties of foam 114 are also difficult to control when applied in the open environment. The application of foam 114 in the open environment is also wasteful as a large quantity of the foam is needed to insure a uniform distribution across the surface of semiconductor wafer 112.

In view of the foregoing, there is a need to conserve the use of foam and to control the physical properties and flow of foam when applied on the surface of the semiconductor wafer.

SUMMARY OF THE INVENTION

Broadly speaking, the present invention fills these needs by providing apparatuses and methods for cleaning a substrate. It should be appreciated that the present invention can be implemented in numerous ways, including as a process, an apparatus, a system, computer readable media, or a device. Several inventive embodiments of the present invention are described below.

In accordance with a first aspect of the present invention, an apparatus for use in processing a substrate is provided. The apparatus includes a brush enclosure extending over a length. The brush enclosure is configured to be disposed over a surface of the substrate and has an open region that is configured to be disposed in proximity to the substrate. The open region extends over the length of the brush enclosure and enables foam from within the brush enclosure to contact the surface of the substrate.

In accordance with a second aspect of the present invention, a brush enclosure for use in processing a substrate is provided. The brush enclosure includes an elongated enclosure configured to enclose a brush. The elongated enclosure is configured to be disposed above a surface of the substrate and has opposite ends that defines a length. Furthermore, the elongated enclosure has an open region along the length of the elongated enclosure. The open region is configured to be disposed above the surface of the substrate and enables a surface of the brush to make contact with the surface of the substrate.

In accordance with a third aspect of the present invention, a substrate cleaning system is provided. The system includes a first brush enclosure and a first brush partially enclosed within the first brush enclosure. The first partially enclosed brush is configured to be disposed above a surface of a substrate. Additionally, the system includes a first drive roller and a

second drive roller whereby the first and second drive rollers are configured to receive an edge of the substrate to support and rotate the substrate when placed below the first partially enclosed brush.

In accordance with a fourth aspect of the present invention, a method for cleaning a substrate is provided. In this method, foam is provided to a surface of the substrate. Next, the surface of the substrate is scrubbed with a brush. Pressure is then provided to the foam and the pressured foam is channeled to produce jammed foam. Brush scrubbing the surface of the substrate and channeling the pressured foam across the surface of the substrate facilitate particles to be removed from the surface of the substrate.

Other aspects and advantages of the invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be readily understood by the following detailed description in conjunction with the accompanying drawings, and like reference numerals designate like structural elements.

Figure 1 is a simplified side view of a conventional system used to clean semiconductor wafers.

Figure 2A is a perspective view of a brush partially enclosed within a brush enclosure, in accordance with one embodiment of the present invention.

Figure 2B is a side view of the brush and the brush enclosure shown in Figure 2A, in accordance with one embodiment of the present invention.

Figure 3 is a perspective view of a substrate cleaning system, in accordance with one embodiment of the present invention.

Figure 4 is a side view of a partially enclosed brush with foam, in accordance with one embodiment of the present invention.

Figures 5A is a magnified side view of the gap region shown in Figure 4, in accordance with one embodiment of the present invention.

Figure 5B is an alternative embodiment of the gap region shown in Figure 5A.

Figure 6 is a flowchart diagram of the method operations for cleaning a substrate, in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION

An invention is disclosed for apparatuses and methods for cleaning a substrate. In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be understood, however, by one of ordinary skill in the art, that the present invention may be practiced without some or all of these specific details. In other instances, well known process operations have not been described in detail in order not to unnecessarily obscure the present invention.

The embodiments described herein provide a brush enclosure to enclose a brush and foam. In particular, the brush enclosure is configured to contain and to control the flow and physical properties of foam. As will be explained in more detail below, the geometry of the brush enclosure creates different cleaning effects within the brush enclosure.

Figure 2A is a perspective view of brush 210 partially enclosed within brush enclosure 212, in accordance with one embodiment of the present invention. For illustrative purposes, brush enclosure 212 includes a cutout section in reference area 220 that shows brush 210 is partially enclosed within the brush enclosure. Brush 210 rotates to dislodge particles and to sweep the particles away from the surface of a substrate. Brush enclosure 212 may be configured to enclose any suitable brush 210 used in processing the substrate. For example, as shown Figure 2A, an exemplary brush 210 has a spline geometry that includes a series of parallel, continuous raised strips at right angles to the curved brush surface. Another exemplary suitable brush 210 has a knobby geometry that includes a set of cylinders raised at right angles to the curved brush surface.

Brush enclosure 212 is an elongated member that extends over length 218. As shown in Figure 2A, length 218 of brush enclosure 212 extends a length of brush 210. However, in another embodiment, length 218 of brush enclosure 212 may be shorter or longer than the length of brush 210. Figure 2A shows brush enclosure 212 having a tubular shape, in accordance with one embodiment of the present invention. However, brush enclosure 212 may not necessarily have a "tubular" shape, but may be any suitable configuration, shape and/or size such as, for example, elongated members with rectangular cross sections, elliptical cross sections, triangular cross sections, circular cross sections, etc., as long as the brush enclosure may be configured in a manner that would enable brush 210 to be partially enclosed.

As will be explained in more detail below, brush enclosure 212 also includes open region 222 and, in one embodiment, additionally includes two opposing flanges 214 that extend

along length and side of open region 222. Brush enclosure 212 is comprised of a chemically inert material. Exemplary chemically inert materials include plastic, Delrin, polyvinylidene fluoride (PVDF), polyethylene terepthalate (PET), etc.

Figure 2B is a side view of brush 210 and brush enclosure 212 shown in Figure 2A, in accordance with one embodiment of the present invention. Here, brush 210 that is partially enclosed within brush enclosure 212 is disposed above substrate 216. As shown in Figure 2B, brush enclosure 212 includes open region 222 and two opposing flanges 214. Open region 222 is configured to be disposed in proximity to a surface of substrate 216 and allows a surface of brush 210 to make contact with the surface of the substrate. In one embodiment, open region 222 extends along complete length of brush enclosure 212. In another embodiment, length of open region 222 is less than the length of brush enclosure 212.

Additionally, flanges 214 extend radially outward from an outer surface of brush enclosure 212. Each flange 214 extends along the length and along a side of open region 222. In one embodiment, each flange 214 extends along the complete length of open region 222. In another embodiment, the length of each flange 214 is less than the length of open region 222. Each flange 214 defines a surface that is substantially parallel to the surface of substrate 216. As used herein, the term "substantially" means that the angle between the surface of each flange 214 and surface of substrate 216 vary from about 0 degrees to about ± 45 degrees. As shown in Figure 2B, brush enclosure 212 includes two flanges 214 on opposite ends. However, in another embodiment, brush enclosure 212 may have one flange 214 instead of two flanges.

Figure 3 is a perspective view of a substrate cleaning system, in accordance with one embodiment of the present invention. As shown in Figure 3, substrate cleaning system includes two brushes 210 partially enclosed in brush enclosures 212, two drive rollers 310, and substrate 216. Drive rollers 310 receive an edge of substrate 216 to support and rotate the substrate. Partially enclosed brushes 210 are oriented relative to each other such that substrate 216 is received between the brushes. Figure 3 shows the use of two partially enclosed brushes 210 to clean substrate 216 . However, in another embodiment, one partially enclosed brush 210 may be used to clean substrate 216. Additionally, in still another embodiment, the substrate cleaning system includes two brushes 210, but with one brush partially enclosed in brush enclosure 212 and the second brush not enclosed within the brush enclosure.

As will be explained in more detail below, the substrate cleaning system uses foam to clean substrate 216. A number of bubbles collectively join to define foam. A bubble is a two-

phase system is which gases are enclosed by liquids. The liquids define a membrane or film that holds and surrounds the gases. In foam, the liquids also exist in the space between the bubbles. In one embodiment, each brush 210 is made of a high-porosity foam such as polyvinyl alcohol (PVA) and can be used as foam generator and foam applicator. To generate foam within brush enclosures 212, gases and liquids are supplied through conduits 312 under pressure to brushes 210. The gases and liquids mix within the porous PVA brushes 210 in such a manner to generate foam. In another embodiment, pre-generated foam is supplied through conduits 312 to brushes 210. To spread foam across the entire surface of substrate 216, drive rollers 310 rotate substrate 216. Alternatively, brushes 210 can move across the surface of substrate 216 to spread foam. Foam may additionally be spread by a combination of rotating substrate 216 and moving brushes 210 across the surface of the substrate.

Figure 4 is a side view of partially enclosed brush 210 with foam 410, in accordance with one embodiment of the present invention. As shown in Figure 4, brush 210 is disposed above substrate 216 and brush enclosure 212 partially encloses the brush and foam 410. The enclosure of brush 210 and foam 410 creates different zones 412, 414, and 416 of cleaning the surface of substrate 216. Within the area defined as Zone A 412, the surface of brush 210 contacts the surface of substrate 216. As brush 210 rotates, the brush physically scrubs the surface of substrate 216 to remove particles. As a result, within Zone A 412, the surface of substrate 216 is cleaned by scrubbing.

On the other hand, within the areas defined as Zone B 412, the surface of substrate 216 is primarily cleaned by chemical treatment with foam 410. Open region 222 of brush enclosure 212 allows foam 410 from within the brush enclosure to contact the surface of substrate 216. As discussed above, foam 410 is comprised of liquids and bubbles of gases. When bubbles within foam 410 rupture on the surface of substrate 216, the rupture releases gases and the gases and liquids are placed in direct contact with surface of substrate 216. A chemical reaction between the gases, liquids, and surface of substrate 216 occurs thereby facilitating removal of particles and layer of material (*e.g.*, organic material layer) from the surface of the substrate.

To chemically treat the surface of substrate 216 with foam 410, the gas is preferably a gas or any combination of gases that will chemically react or will facilitate a chemical reaction when placed in direct contact with another material. Exemplary gases that react with contamination include ozone (O_3), oxygen (O_2), hydrochloric acid (HCl) and hydrofluoric acid (HF), and non-reactive gasses such as nitrogen (N_2) and argon (Ar). The gas may also include

any combination of gases such as: ozone (O_3) and nitrogen (N_2); ozone (O_3) and argon (Ar); ozone (O_3), oxygen (O_2) and nitrogen (N_2); ozone (O_3), oxygen (O_2) and argon (Ar); ozone (O_3), oxygen (O_2), nitrogen (N_2) and argon (Ar); oxygen (O_2) and argon (Ar); oxygen (O_2) and nitrogen (N_2); and oxygen (O_2), argon (Ar) and nitrogen (N_2). An embodiment of the present invention uses ozone as gas because ozone, when combined with water, chemically reacts with an organic material on the surface of substrate 216. The organic material may be an organic photoresist material, which is commonly used in semiconductor photolithography operations. Nitrogen can be combined with ozone to increase the concentration of ozone in the bubbles.

The liquid used to generate foam 310 is a liquid or any combination of liquids that will chemically react or will facilitate a chemical reaction when placed in direct contact with another material. The liquid may be a semi-aqueous or aqueous solution of deionized water (DIW) containing suitable cleaning fluids. Examples of liquids include water (H_2O); deionized water (DIW); water (H_2O) and cleaning fluid; water (H_2O) and surfactant; water (H_2O), cleaning fluid, and surfactant; deionized water (DIW) and surfactant; and deionized water (DIW), cleaning fluid and surfactant. As discussed above, an embodiment of the present invention uses water as the liquid because water enables or facilitates the chemical reaction between ozone and an organic photoresist material.

Within the areas defined as Zone C 416, the surface of substrate 216 is primarily cleaned by the attraction of particles to the gas/liquid interfaces of bubbles. As shown in Figure 4, the space between the surface of each flange 214 and surface of substrate 216 defines gap 224. Gap 224 is maintained to induce a non-Newtonian flow field. In one embodiment, dimension of gap 224 ranges from about 0.1 mm to about 5 mm. As used herein, the term "about" means that the specified dimension or parameter may be varied within an acceptable manufacturing tolerance for a given application. In one embodiment, the acceptable manufacturing tolerance is ±10%.

Pressure is applied to foam 410 within brush enclosure 212 and the foam is channeled into gap 224 (*i.e.*, Zone C 416) to produce jammed foam. Jammed foam is produced by the application of force to compress foam 410. When compressed within gap 224, the bubbles within foam 410 deform in shape and rearrange into a more closely packed configuration. In effect, the pressure and geometry of gap 224 causes foam 410 to change from a meta-stable position to a more stable position within Zone C 416.

As pressure channels foam 410 within brush enclosure 212 through gap 224, shear force is created locally between the bubbles of jammed foam. The shear force causes the bubbles to

move locally with relationship to each other. The local movements of bubbles caused by the shear force release bursts of energy, and this energy is transferred to the surface of substrate 216 to facilitate the removal of particles from the surface of the substrate. Specifically, the bubbles within the jammed foam want to be at a minimum energy state, where all the angles between the bubbles are approximately 120 degrees. When shear force causes a bubble at a minimum energy state to pass over another bubble, the angles between the bubbles change, and the change of angle results in a higher energy state. In effect, a change of angles between bubbles equates to a change of energy. Thus, the energy is released not by bubbles rupturing, but by the local rearrangement of bubbles within the jammed foam.

As shown in Figure 4, brush enclosure 212 may additionally include removing conduits 450 located within flanges 214, in accordance with one embodiment of the present invention. Removing conduits 450 are configured to remove foam 410, liquid, particles, etc. from surface of substrate 216 by applying vacuum. In another embodiment, conduits 450 could also be configured to provide deionized water (DIW) and/or chemical rinse to facilitate foam removal. In still another embodiment, additional conduits 450 may supply an additional chemical and/or gas, such as isopropyl alcohol (IPA), to reduce the surface tension of liquids on the surface of water as a means of removing the liquid from the surface of substrate 216.

Figures 5A and 5B are magnified side views of the gap region shown in Figure 4, in accordance with one embodiment of the present invention. As shown in Figures 5A and 5B, gap region shows brush 210 disposed above substrate 216 partially enclosed within brush enclosure 212. Brush enclosure 212 includes flange 214 and the space between the surface of the flange and surface of substrate 216 defines gap 224. Different gap 224 geometries may be used to manipulate the mechanical properties and dimensions of foam 410 and the bubbles within the foam. The combination of changing the mechanical properties and chemical properties of foam 410 provides cleaning process flexibility by changing in-situ properties of the foam for different cleaning requirements. For instance, as shown in Figure 5A, a small gap 224 results in small bubbles within the gap. Since gap 224 is small, pressure within brush enclosure 212 is large and, as a result, foam 410 exits gap 224 at a high velocity. The combination of smaller bubble size and high foam viscosity increases the shearing force between the bubbles. Higher shearing force results in larger energy transferred to surface of substrate 216 when bubbles within jammed foam locally rearrange.

On the other hand, as shown in Figure 5B, a larger gap 224 results in larger bubbles within the gap. Since gap 224 is large, pressure within brush enclosure 212 is less and, as a

result, foam 410 exits the gap at a lower velocity. The combination of larger bubble size and lower viscosity facilitates the removal of particles from vias and trenches. Since different gap geometries create different cleaning properties, the two flanges on opposite sides of brush enclosure 212 may be configured to have different geometries, in accordance with one embodiment of the present invention. For example, one flange 214 may be configured to have a small gap to create a higher shear force while the opposite flange 214 on the same brush enclosure 212 may be configured to have a larger gap to remove particles from vias and trenches. Thus, in this embodiment, brush enclosure 212 may be configured to satisfy two different cleaning requirements.

Figure 6 is a flowchart diagram of the method operations for cleaning a substrate, in accordance with one embodiment of the present invention. Starting in operation 610, foam is provided to a surface of the substrate. At the area where a surface of a brush makes contact with a surface of the substrate, the surface of the substrate is physically scrubbed by the brush in operation 612. Simultaneously, within an area created by a brush enclosure that is between the area where the brush makes contact with the surface of the substrate and an area defined by a gap, the surface of the substrate is primarily cleaned by chemical treatment with foam in operation 613. As discussed above, the chemical treatment facilitates the removal of particles and films from the surface of the substrate by placing gases and liquids, through the rupture of bubbles within the foam, in direct contact with the surface of substrate. At the same time, pressure is provided to the foam in operation 614 and, as a result, the pressured foam is channeled to produce jammed foam in operation 616. In particular, the foam is channeled into a gap created by the brush enclosure. The gap is defined by a space between a surface of the brush enclosure (*e.g.*, a flange) and the surface of the substrate. The pressure on the foam and geometry of the gap compress the foam to produce the jammed foam. The local rearrangement of bubbles within the jammed foam releases energy that facilitates the removal of particles and films from the surface of the substrate.

In sum, the above described invention provides apparatuses and methods for use in cleaning a substrate. The enclosure of foam reduces the amount of foam needed to cover a particular surface area of the substrate. Furthermore, the geometry of the brush enclosure can specifically direct the flow of foam and control the physical properties of foam to better facilitate the removal of particles and film from the surface of the substrate. As a result, the brush enclosure simultaneously allows different cleaning actions (*e.g.*, scrubbing, chemical

treatment, and rearrangement of bubbles within jammed foam) to be conducted on a surface area of the substrate.

Although the foregoing invention has been described in some detail for purposes of clarity of understanding, it will be apparent that certain changes and modifications may be practiced within the scope of the appended claims. Accordingly, the present embodiments are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details given herein, but may be modified within the scope and equivalents of the appended claims.

What is claimed is:

CLAIMS

1. An apparatus for use in processing a substrate, comprising:

a brush enclosure extending over a length, the brush enclosure configured to be disposed over a surface of the substrate, the brush enclosure having an open region that is configured to be disposed in proximity to the substrate, the open region enabling foam from within the brush enclosure to contact the surface of the substrate when the substrate is present, the open region extending over the length of the brush enclosure.

2. The apparatus of claim 1, wherein the brush enclosure has a tubular shape.

3. The apparatus of claim 1, wherein the length of the brush enclosure is configured to extend a length of a brush.

4. A brush enclosure for use in processing a substrate, comprising:

an elongated enclosure configured to enclose a brush, the elongated enclosure being configured to be disposed above a surface of the substrate, the elongated enclosure having opposite ends defining a length and having an open region along the length of the elongated enclosure, the open region configured to be disposed above the surface of the substrate enabling a surface of the brush when the brush is present to make contact with the surface of the substrate when the substrate is present.

5. The brush enclosure of claim 4, further comprising:

a flange along the length of the elongated enclosure extending radially outward from an outer surface of the elongated enclosure, the flange defining a surface being substantially parallel to the surface of the substrate when the substrate is present.

6. The brush enclosure of claim 5, wherein a space between the surface of the flange and the surface of the substrate when the substrate is present defines a gap, the gap enabling production of jammed foam.

7. The brush enclosure of claim 6, wherein the gap has a dimension from about 0.1 mm to about 5 mm.

8. The brush enclosure of claim 5, wherein the flange has a conduit configured to remove liquid resulting from collapse of jammed foam from the surface of the substrate when the substrate is present.

9. The brush enclosure of claim 4, wherein the length of the brush enclosure is configured to extend a length of a brush.

10. The brush enclosure of claim 4, wherein the open region extends over the length of the elongated enclosure.

11. A substrate cleaning system, comprising:

a first brush enclosure;

a first brush partially enclosed within the first brush enclosure, the first partially enclosed brush being configured to be disposed above a surface of a substrate;

a first drive roller; and

a second drive roller, the first and second drive rollers being configured to receive an edge of the substrate to support and rotate the substrate when placed below the first partially enclosed brush.

12. The substrate cleaning system of claim 11, further comprising:

a second brush enclosure;

a second brush partially enclosed within the second brush enclosure, the second partially enclosed brush being oriented relative to the first partially enclosed brush configured to receive the substrate between the first and second partially enclosed brushes.

13. A method for cleaning a substrate, comprising:

providing foam to a surface of the substrate;

brush scrubbing the surface of the substrate;

providing pressure to the foam; and

channeling the pressured foam to produce jammed foam,

wherein the method operations of brush scrubbing the surface of the substrate and channeling the pressured foam across the surface of the substrate facilitate particles to be removed from the surface of the substrate.

14. The method of claim 13, further comprising:

chemically treating the surface of the substrate with the foam, the chemical treatment facilitating the particles to be removed from the surface of the substrate.

15. The method of claim 14, wherein the method operation of chemically treating the surface of the substrate with the foam includes,

rupturing bubbles within the foam to release gases and liquids onto the surface of the substrate, the gases and liquids facilitating removal of the particles from the surface of the substrate.

16. The method of claim 15, wherein the gases are defined by one or more of ozone (O_3), oxygen (O_2), hydrochloric acid (HCl), hydrofluoric acid (HF), nitrogen (N_2), and argon (Ar).

17. The method of claim 15, wherein the liquids are defined by one or more of water (H_2O), deionized water (DIW), cleaning fluid, and surfactant.

18. The method of claim 13, wherein the pressure on the jammed foam creates a shear force on the jammed foam.

19. The method of claim 13, wherein the method operation of providing pressure to the foam includes,

applying gases and liquids through a brush, the application of the gases and the liquids enabling the production of pressure to the foam.

20. The method of claim 13, wherein the method operation of channeling the pressured foam to produce jammed foam includes,

channeling the pressured foam into a gap, the gap being defined by a space between a surface of a brush enclosure and the surface of the substrate.