The present invention provides an improved end-effector which reduces back surface contamination (the "fingerprint") on wafer surfaces during the handling of the wafer during wafer manufacturing, more particularly, CMP/cleaning processes. The end-effector has a vacuum pocket with various footprint sizes, shapes and configurations with an area of about 231-451 mm². The area surrounding the vacuum pocket (or pockets) may be raised so that the wafer contacts the end-effector only in proximity to the vacuum pocket. The end-effector may further be coated with a friction reducing coating that helps to generate low particulate generation and generates less wear on silicon wafer surfaces.
ADVANCED WAFER PASSIVE END-EFFECTOR

BACKGROUND OF THE INVENTION

1. Technical Field

The present invention relates generally to end-effectors for handling wafers during planarization, polishing and cleaning, and, more particularly, to end-effectors for use in clean room applications and which lower back surface contamination by use various vacuum pockets footprints, shapes and sizes and low friction coatings.

2. Background of the Invention

Wafers of various forms are well known in industry. As is generally known in the electronics industry, wafers are often used to store information and perform functions, particularly in the area of integrated circuits. Examples of common wafers include semiconductor wafers, magnetic disks, optical disks or other work pieces and are generally in the form of a flat, substantially planar disk.

The processes for manufacturing the wafers are also well known. For example, manufacturing a semiconductor wafer might include slicing a wafer from a silicon ingot and then polishing, cleaning, rinsing, and drying the wafer to remove any debris from the surface of the wafer. The polishing, cleaning and planarization may be performed on a typical chemical mechanical planarization (CMP) machine 100 such as the machine shown in Figure 1. As illustrated and described in further detail below, various handling devices 110 are used for transporting wafers 120, from one station to the next in the various manufacturing operations. For example, Figure 1 shows a handling device 110 connected to a robotic arm 130 transferring a wafer 120 from a wafer cassette 140 to a rinsing station 150.

The wafers, in particular, semiconductor wafers, must be planarized and polished to remove excess material and imperfections and to prevent problems such as electrical shorts. Similarly, in the manufacture of optical disks, removal of debris on the surfaces of the disks is important because the debris can cause voids in recorded information on the disks.

At each step of the process, as imperfections and debris are reduced or eliminated, the wafers become increasingly more valuable. For example, a typical silicon wafer, prior to any processing, may cost $80-500. However, after the wafer has been planarized, polished and cleaned, it is often worth $20,000-$80,000 or more. Thus, the handling of the wafers during these processes, particularly during the final manufacturing steps, needs to ensure that the
wafers are not “contaminated” or damaged by adding imperfections or debris.

Various wafer handling devices have been developed in attempts to prevent or reduce damage to the wafers during their manufacture. For example, typical devices for handling wafers are edge grippers and standard end-effectors. Referring to Figures 1 and 2, a standard end-effector 200 is shown. The end-effector 200 typically comprises a member 250 with a vacuum line 210 running from a connecting end 220 connected to the robotic arm 130 and a vacuum end 230 with a vacuum pocket 240. The robotic arm 130 moves the end-effector 200 to a wafer cassette 150 and contacts the wafer 120 at the vacuum end 230. When the vacuum (negative pressure) is activated, the vacuum secures the wafer 120 to the end-effector 200.

Once so secured, the robotic arm 130 can be moved about and, accordingly, the wafer 120 can be transferred to another station, e.g., the rinsing station.

It is often economically desirable to increase the speed of the wafer manufacturing operations. One manner of doing so is to increase the speed at which the robotic arms and handling devices move the wafers. However, as the robotic arms and handling devices begin to move faster, due to the dynamic forces on the wafer during transport, the wafers become more likely to slip or become displaced from the handling devices. This movement can damage the wafers and/or create defects on the wafer surface due to the contact between the wafer and the handling device or through the wafer detaching from the handling device.

To prevent the wafer movement or detachment, the strength of the vacuum applied to the wafer may be increased. However, the optimum range of pressures for the vacuum source is about (-)10-12 psi, with a maximum typical vacuum pressure of (-)12.5 psi. Once the vacuum is increased to over 12.5 psi, the wafer may be damaged by the vacuum. The damage occurs through deformation of the wafer caused by the increased pressure of the wafer against the end-effector. In particular, the pressure of the vacuum which secures the wafer to the end-effector creates back surface contamination, or a “finger print,” on the wafer surface. Generally, the larger the contact area between the wafer and end-effector, the larger the fingerprint will be. Figure 3 is a surface scan showing the number of defects on a wafer prior to handling by the end-effector. The pre-handling fingerprint is shown as a number of defects 310. Prior to handling the number of defects on the wafer surface is typically in the range of 5-10 defects. However, Figure 4 shows the same wafer of Figure 3 after handling by a standard end-effector. The pressure of the vacuum from the standard end-effector has increased the number of defects 410 to nearly 1400 defects. Generally, silicon wafers generally must have no more than 200-250 defects, largely concentrated at the end-effector contact points. Thus, the
defects shown in Figure 4 exceeds this range and cannot be used. Such increased numbers of defects are typical of standard end-effectors, and thus they cannot be used. This problem becomes even more prevalent in clean room applications where vary low defect wafers are required.

Alternative devices have been developed to prevent wafer back surface contamination on the wafers as well. For example, edge grippers may be used. Figures 5a-c show active edge grippers 500. The edge gripper 500 includes a partial ring 510 with a groove 520 within the gripper's 500 inner circumference. A rotating retaining device 530 for holding the wafer is also provided. During operation, the ring 510 is positioned around the wafer and the retaining device 530 rotates upward and closes on the wafer. The groove 520 centers the wafer and maintains it away from the base of the gripper 500. Thus, the contact points between the wafer and the gripper 500 exist only at portions of the edges of the wafer and back spray contamination is reduced.

However, although edge grippers may reduce wafer back surface contamination on the wafers, they are typically expensive and more complex to use than standard end-effectors. Edge grippers comprise multiple moving parts, all of which are subject to failure. Additionally, each edge gripper must be customized to the particular wafer size to be handled. Should varying wafer sizes be used on the same CMP tool, the edge grippers must be changed to correspond to the particular wafer size. Multiple edge grippers must be purchased if varying wafer sizes are to be manufactured. Typical edge grippers can cost upwards of $3500. Thus, edge grippers add expense to CMP tools in the form of additional components and time involved in changing the grippers for varying wafer sizes.

Accordingly, there is a need for wafer handling devices which reduce wafer back surface contamination, which are less expensive than existing handling devices and are capable of handling varying wafer sizes.

**SUMMARY OF THE INVENTION**

The present invention provides an improved end-effector which reduces back surface contamination on a wafer surface during the handling of the wafer during various wafer manufacturing processes. In accordance with the present invention, an end-effector is provided with a vacuum pocket which may have various footprint sizes (the area of contact) and shapes and having an optimum area of about 231-451 mm². The various footprint sizes and shapes of the vacuum pocket provide varying securment forces which secure the wafer to the end-
effector. In accordance with one embodiment of the present invention, the area surrounding the vacuum pocket (or pockets) is raised such that a wafer only contacts the end-effector in proximity to the vacuum pocket. In accordance with another aspect of the present invention, the end-effector has a friction reducing coating. The friction reducing coating may contribute to reducing particulate generation and contamination to the back surface of the wafer. The various footprint and shapes may provide additional support to the wafer to prevent deformation during the handling process.

BRIEF DESCRIPTION OF THE DRAWINGS

Additional aspects of the present invention will become evident upon reviewing the non-limiting embodiments described in the specification and the claims taken in conjunction with the accompanying figures, wherein like numerals designate like elements, and:

Figure 1 is top plan view of a typical CMP tool;
Figure 2 is a perspective view of a standard end-effector;
Figure 3 is a surface scan of a wafer prior to handling by a standard end-effector;
Figure 4 is a surface scan of a wafer after handling by a standard end-effector;
Figures 5a-c are various embodiments of active edge grippers;
Figure 6 is an exemplary embodiment of an improved end-effector of the present invention;
Figure 7a,b are exemplary embodiments of the cross-sections of the vacuum pocket of the end-effector of the present invention;
Figures 8a-c are alternative embodiments of the cross-section of the vacuum pocket of the end-effector of the present invention;
Figure 9 is a surface scan of a wafer prior to handling by the improved end-effector of the present invention; and
Figure 10 is a surface scan of a wafer after handling by the improved end-effector of the present invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

The following descriptions are only of exemplary embodiments of the invention only, and are not intended to limit the scope, applicability, or configuration of the invention in any way. Rather, the following description provides convenient illustrations for implementing different embodiments of the invention. As will become apparent, various changes may be made in the function and arrangement of the elements described in these preferred
embodiments without departing from the spirit and scope of the invention as set forth in the appended claims.

In general, in accordance with the present invention, an improved end-effector which reduces back surface contamination on a wafer surface during the handling of the wafer during various wafer manufacturing steps is disclosed. In particular, with reference to Figure 6, in accordance with a preferred embodiment of the present invention, an improved end-effector 600 is provided. End-effector 600 is preferably comprised of a ceramic material such as Alumina (99.5% Al₂O₃), although it should be appreciated that end-effector 600 may be manufactured from various alternative materials including other ceramics, plastics, metals, composites and the like.

In accordance with the present embodiment, end-effector 600 is suitably comprised of an end-effector arm 610 with a connection end 620 and a wafer contact end 630. Connection end 620 is provided for connecting end-effector 600 to a robotic arm of a CMP tool (not shown). In the present embodiment, connection end 620 is fastened to the robotic arm with standard bolts and/or screws. However, in accordance with various alternative embodiments, other securing means may be used to fasten end-effector 600 to the robotic arm such as welding, brazing, epoxies, physical integration of end-effector 600 and robotic arm (to form one unit) and the like. Accordingly, the preferred embodiment of end-effector 600 is provided with various numbers of holes 640 at connection end 620 for bolting end-effector 600 to the robotic arm. Preferably ten holes 640 are provided, though any number of holes 640 may also be used as will be dictated by factors such as speed, strength and the range of movement during operation of end-effector 600.

As described in additional detail below, wafer contact end 630 is the end of end-effector 600 which contacts wafer 120 and which suitably supports and secures wafer 120 during operation of the CMP machine. A vacuum pocket 650 is suitably provided at wafer contact end 630. In accordance with the present invention, vacuum pocket 650 has an optimum surface area of about 231 to about 451 mm². Preferably, with reference to Figures 6 and 7a, the vacuum pocket area is a single pocket with a substantially “H-X” shape and footprint size. However, in accordance with various alternative aspects of the present invention, vacuum pocket area may suitably be comprised of various alternative shapes and foot print sizes and/or may be comprised of multiple vacuum pockets, typically dictated by the amount of force need to secure the wafer 120 during the handling/transport processes. For example, Figure 7b shows an “W-X” configuration. Likewise, with momentary reference to Figure 8a-d, various other
alternative configurations of vacuum pocket 650 are illustrated. For example, Figure 8a shows a configuration of vacuum pocket having a substantially X-shape. In accordance with yet another embodiment, vacuum pocket 650 comprises a plurality of pockets. For example, Figure 8b illustrates an embodiment of the present invention comprising four vacuum pockets 650 arranged in a “square” fashion. Figure 8c shows a vacuum pocket 650 using a combination of circular pockets and a substantially square shaped pocket. Thus, it should be apparent that nearly any configuration of vacuum pockets 650 may be used wherein the optimum area of vacuum pocket 650 is in the range of about 231-451 mm$^2$.

With reference to Figure 6, according to another aspect of the preferred embodiment, an area 670 surrounding vacuum pocket 650 at wafer contact end 630 is raised above a portion of end-effector 600 between connecting end 620 and wafer contact end 630. Preferably, raised area 670 is proximate to vacuum pocket 650 at wafer contact end 630. Preferably, raised area 670 is elevated about 2 mm above end-effector area 610, although it should be apparent that the elevation of raised area 670 may vary depending on the particular application. As will be described below, raised area 670 suitably prevents contact of wafer 120 with end-effector 600 at any portion of end-effector 600 other than at wafer contact end 630 of end-effector 600.

In accordance with yet another aspect of the present invention, raised area 670 of wafer contact end 630 is suitably coated with a low friction material. Preferably, low friction material is Teflon (PTFE) with a thickness of about 30-200 microns, though in accordance with various alternative embodiments, low friction material 680 may suitably comprise any friction reducing material or substance such as, for example, Halar, diamond light carbon (DLC) or the like. Additionally, as should be appreciated, the thickness of low friction material 680 may also vary according to the particular application.

With continuing reference to Figure 6, a vacuum line 690 is suitably provided between vacuum pocket 650 and a vacuum source (not shown). In the present exemplary embodiment, vacuum line 690 is an aperture running from vacuum pocket 650 within end-effector 600 and exiting end-effector 600 at connection end 620 at the robotic arm (not shown). However, in accordance with various alternative embodiments, vacuum line 690 can be a separate line, such as a vacuum tube or pressure hose, which runs outside the structure of end-effector 600.

The operation of a preferred embodiment of the present invention as implemented in a typical CMP machine follows. End-effector 600 attached to the robotic arm is manipulated into wafer cassette 150 and wafer contact end 630 contacts wafer 120. A vacuum, preferably in the range of 10-12 psi is provided via vacuum line 690 to vacuum pocket 650. The vacuum pulls
wafer 120 to raised area 670, securing wafer to end-effector 600 such that minimal contact is created between end-effector 600 and wafer 120. Wafer 120 is thus secured to end-effector 600. End-effector 600 and wafer 120 are then transported by the robotic arm and end-effector 600 as so desired. For example, wafer can be transported to a polishing or planarization station.

Upon reaching the desired station, (e.g., the planarization station) the vacuum is removed and wafer 120 is no longer secured to end-effector 600. End-effector 600 then moves out of the way, and the appropriate processing step can begin. As should be apparent, at the completion of a particular processing step, a vacuum may be re-applied to end-effector 600 and the processed wafer can be transported to still another processing station.

As demonstrated below, the above described embodiments of the present invention, provide superior performance to existing wafer handling devices. For example, Figure 9 shows a surface scan of a wafer prior to handling by the improved end-effector 600 of the present invention. On this wafer, there are 5 defects 910. In contrast, Figure 10 shows the surface scan of the wafer after handling by the present invention are shown. The wafer has only 69 defects 1010; well below the 200-250 range of defects for acceptable wafers.

Additionally, the present invention provides an end-effector which generally encounters about 90% less wear than with existing end-effectors. The end-effector can be moved at virtually any speed or distance without wafer displacement or the wafer becoming detached from the end-effector, and without an increase in vacuum pressure over the (-)12.5 psi limit.

Furthermore, the end-effector of the present invention provides about 80% less friction than existing end-effectors at the area of wafer contact. Finally, the current cost of the end-effector of the present invention is approximately ten percent (10%) more than existing ceramic vacuum end-effectors, however the cost of the end-effector of the present invention remains seventy percent (70%) less than standard edge grippers. Still further, footprint shapes such as the H-X or W-X configurations may suitably reduce the total contact area between the wafer and end-effector as only raised area 670 contacts the wafer.

Lastly, while the principles of the invention have been described in illustrative embodiments, it should be apparent that many modifications of structure, arrangement, proportions, the elements, materials and components of the end-effector, used in the practice of the invention and not specifically described, may be varied and particularly adapted for specific applications and operating requirements without departing from those principles.
I claim:

1. A wafer handling device comprising:
   an end-effector arm, and
   a vacuum pocket located at a wafer retaining end of said end-effector member,
   wherein said vacuum pocket has a vacuum pocket surface area of about 231 to 451 mm$^2$.

2. The wafer handling device of claim 1, wherein said wafer retaining end is coated
   with a low friction material.

3. The wafer handling device of claim 2, wherein said low friction material has a
   coefficient of friction of less than about 0.2.

4. The wafer handling device of claim 2, wherein a raised area surrounds said
   vacuum pocket.

5. The wafer handling device of claim 4, wherein said raised area is about 2 mm
   above a top surface of said end-effector area.

6. The wafer handling device of claim 4, wherein said raised area is about 0 to 2
   mm above a top surface of said end-effector area.

7. The wafer handling device of claim 2, wherein said low friction material
   comprises Teflon.

8. The wafer handling device of claim 2, wherein said low friction material
   comprises diamond light carbon.

9. The wafer handling device of claim 2, wherein said low friction material is
   Halar.

10. The wafer handling device of claim 1, wherein said vacuum pocket is formed in
    a H-X configuration.

11. The wafer handling device of claim 1, wherein said vacuum pocket surface is
    formed in a W-X configuration.

12. The wafer handling device of claim 1, wherein said vacuum pocket is formed as
    a plurality of vacuum pockets.

13. The wafer handling device of claim 1, wherein said vacuum pocket surface area
    is about 231 mm$^2$.

14. The wafer handling device of claim 1, wherein said vacuum pocket surface area
    is about 271 mm$^2$.

15. The wafer handling device of claim 1, wherein said vacuum pocket is about
    332 mm$^2$. 
16. The wafer handling device of claim 1, wherein said vacuum pocket is about 343 mm².

17. The wafer handling device of claim 1, wherein said vacuum pocket area is about 451 mm².

18. A wafer handling device comprising:
   an end-effector arm, and
   a raised area proximate to a wafer retaining end of said end-effector member, with a vacuum pocket, wherein said vacuum pocket has a vacuum pocket surface area of about 231 to 451 mm².

19. The wafer handling device of claim 18, wherein said vacuum pocket surface area is formed in a H-X configuration.

20. The wafer handling device of claim 18, wherein said vacuum pocket surface area is formed in a W-X configuration.
PRIOR ART

FIG. 5a
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 H01L21/00

According to International Patent Classification (IPC) or to both national classification and IPC.

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used):

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
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<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim</th>
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<td>Y</td>
<td>US 4 981 315 A (POLI ET AL.)&lt;br&gt;1 January 1991 (1991-01-01)&lt;br&gt;the whole document</td>
<td>1, 4, 13-18</td>
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<td>Y</td>
<td>US 4 869 481 A (YABU ET AL.)&lt;br&gt;26 September 1989 (1989-09-26)&lt;br&gt;abstract; figures 1, 2&lt;br&gt;column 4, line 45-60</td>
<td>1, 4, 13-18</td>
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<td>A</td>
<td>PATENT ABSTRACTS OF JAPAN&lt;br&gt;vol. 014, no. 461 (E-0987),&lt;br&gt;5 October 1990 (1990-10-05)&lt;br&gt;&amp; JP 02 186656 A (HITACHI LTD),&lt;br&gt;20 July 1990 (1990-07-20)&lt;br&gt;abstract</td>
<td>1, 2, 4, 8, 18</td>
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X Further documents are listed in the continuation of box C.

X Patent family members are listed in annex.

Special categories of cited documents:

*A* document defining the general state of the art which is not considered to be of particular relevance

*E* earlier document but published on or after the international filing date

*L* document which may throw doubts on priority, claims or which is cited to establish the publication date of another invention or other special reasons (as specified)

*C* document referring to an oral disclosure, use, exhibition or other means

**M** document published prior to the international filing date but later than the priority date claimed

**T** later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

**P** document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

**Y** document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

**S** document member of the same patent family

Date of the actual completion of the international search: 24 April 2001

Date of mailing of the international search report: 07/06/2001

Name and mailing address of the ISA:

European Patent Office, P.O. 5818 Patentlaan 2 NL-2280 HV Rosapino Tel: (+31-70) 340-3040, Tx 31 651 epo nl, Fax: (+31-70) 340-3016

Authorized officer: Oberle, T
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