According to one embodiment, a CMP apparatus includes a supplying portion supplying a slurry to a surface portion of a polishing pad including water-soluble particles, a holding portion contacting an object to be polished with the surface portion of the polishing pad in a condition of holding the object, a temperature setting portion on the surface portion of the polishing pad, the temperature setting portion setting a temperature of the surface of the polishing pad. A control portion executes a first polishing step and a second polishing step after the first polishing step, the object is polished in a condition of setting the temperature of the surface of the polishing pad within a first temperature range in the first polishing step, and the object is polished in a condition of setting the temperature of the surface of the polishing pad within a second temperature range in the second polishing step.
<table>
<thead>
<tr>
<th>Slurry</th>
<th>Polishing pad</th>
<th>Dissolved threshold value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>a</td>
<td>T1</td>
</tr>
<tr>
<td>A</td>
<td>b</td>
<td>T2</td>
</tr>
<tr>
<td>A</td>
<td>c</td>
<td>T3</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>B</td>
<td>a</td>
<td>T4</td>
</tr>
<tr>
<td>B</td>
<td>b</td>
<td>T5</td>
</tr>
<tr>
<td>B</td>
<td>c</td>
<td>T6</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

**FIG. 5**

**FIG. 6**
Start

Set dissolved threshold value based on input information (e.g., slurry, polishing pad)
※ When water-soluble particles are dissolved at dissolved threshold value or more

Set temperature of surface portion of polishing pad within first temperature range
(less than dissolved threshold value)

Pass torque current value > torque through first change point?

Set temperature of surface portion of polishing pad within second temperature range
(more than dissolved threshold value)

Pass torque current value > torque through second change point?

Set temperature of surface portion of polishing pad within first temperature range
(less than dissolved threshold value)

Return surface portion of polishing pad to initial state

End

FIG. 7
<table>
<thead>
<tr>
<th>Comparative example 1</th>
<th>Elasticity is constant in CMP step</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Polishing step</td>
</tr>
<tr>
<td></td>
<td>Low elasticity in surface portion only</td>
</tr>
<tr>
<td></td>
<td>High elasticity</td>
</tr>
<tr>
<td>Embodiment</td>
<td>Elasticity changes in CMP step</td>
</tr>
<tr>
<td></td>
<td>First polishing step</td>
</tr>
<tr>
<td></td>
<td>Second polishing step</td>
</tr>
<tr>
<td></td>
<td>Low elasticity in surface portion only</td>
</tr>
<tr>
<td></td>
<td>All high elasticity</td>
</tr>
</tbody>
</table>

**FIG. 16**
Set dissolved threshold value based on input information (e.g., slurry, polishing pad)
※ When water-soluble particles are dissolved at dissolved threshold value or less

Set temperature of surface portion of polishing pad within first temperature range
(more than dissolved threshold value)

ST1

ST2

Pass torque current value I torque through first change point?

Yes

Set temperature of surface portion of polishing pad within second temperature range
(less than dissolved threshold value)

No

ST3

Yes

ST4

Pass torque current value I torque through Second change point?

No

ST5

Yes

ST6

Return surface portion of polishing pad to initial state

ST7

End

FIG. 17
FIG. 18

FIG. 19

FIG. 20
Start

Set dissolved threshold value based on input information (e.g., slurry polishing pad)  ※When water-soluble particles are dissolved at dissolved threshold value or more  ST1

Set temperature (initial value) of surface portion of polishing pad to value less than dissolved threshold value  Control increase rate of temperature  ST2

No  ST3

Pass torque current value I torque through first change point?  Yes

Set temperature of surface portion of polishing pad within second temperature range (more than dissolved threshold value) by controlling increase rate of temperature  ST4

No  ST5

Pass torque current value I torque through second change point?  Yes

Set temperature of surface portion of polishing pad within first temperature range (less than dissolved threshold value) by cooling mechanism  ST6

Return surface portion of polishing pad to initial state  ST7

End

FIG. 24
**CMP APPARATUS, POLISHING PAD AND CMP METHOD**

**CROSS-REFERENCE TO RELATED APPLICATIONS**

This application is based upon and claims the benefit of priority from prior Japanese Patent Application No. 2011-040468, filed Feb. 25, 2011, the entire contents of which are incorporated herein by reference.

**FIELD**

Embodiments described herein relate generally to a CMP apparatus, a polishing pad and a CMP method.

**BACKGROUND**

In semiconductor processes, Chemical Mechanical Polishing (CMP) is used to planarize a dielectric film, metal film, polysilicon film and the like embedded in a groove. In next-generation devices of the 32-nm generation and thereafter, it is necessary to ensure a high level of flatness and reduce polishing scratches at the same time in the CMP step to reduce focus errors and improve yields in an exposure step accompanying micropatterning.

**BRIEF DESCRIPTION OF THE DRAWINGS**

FIGS. 1 and 2 are diagrams showing a CMP apparatus;

FIG. 3 is a diagram showing a polishing pad;

FIG. 4 is a diagram showing an object to be polished,

FIG. 5 is a diagram showing a management table;

FIG. 6 is a diagram showing a change in torque current value;

FIG. 7 is a flowchart showing a first example of an operation of the CMP apparatus;

FIG. 8 is a diagram showing a temperature change in a surface portion of the polishing pad;

FIGS. 9 to 12 are diagrams showing a CMP method;

FIG. 13 is a diagram showing the object to be polished in a first polishing step;

FIG. 14 is a diagram showing the object to be polished in a second polishing step;

FIG. 15 is a diagram showing the object to be polished when the second polishing step is finished;

FIG. 16 is a diagram showing elasticity in a CMP step;

FIG. 17 is a flowchart showing a second example of the operation of the CMP apparatus;

FIG. 18 is a diagram showing the temperature change in the surface portion of the polishing pad;

FIGS. 19 to 22 are diagrams showing the CMP method;

FIG. 23 is a diagram showing a modification of the CMP apparatus;

FIG. 24 is a flowchart showing a third example of the operation of the CMP apparatus;

FIG. 25 is a diagram showing the temperature change in the surface portion of the polishing pad;

FIG. 26 is a diagram showing the CMP method; and

FIGS. 27 to 29 are diagrams showing the CMP method.

**DETAILED DESCRIPTION**

In general, according to one embodiment, a CMP apparatus comprising: a supplying portion supplying a slurry to a surface portion of a polishing pad including water-soluble particles; a holding portion contacting an object to be polished with the surface portion of the polishing pad in a condition of holding the object; a temperature setting portion on the surface portion of the polishing pad, the temperature setting portion setting a temperature of the surface of the polishing pad; and a control portion controlling an operation of the supplying portion, the holding portion and the temperature setting portion, wherein the control portion executes a first polishing step and a second polishing step after the first polishing step, the object is polished in a condition of setting the temperature of the surface of the polishing pad within a first temperature range in the first polishing step, and the object is polished in a condition of setting the temperature of the surface of the polishing pad within a second temperature range in the second polishing step.

The embodiment relates to, for example, a CMP apparatus, a polishing pad, and a CMP method used in a planarization process in a method of manufacturing a semiconductor device. In the planarization process, ensuring a high level of flatness and reducing polishing scratches of a dielectric film, metal film, polysilicon film and so on embedded in a groove poses a challenge.

However, flatness and polishing scratches have a correlation with elasticity of the polishing pad. For example, increased elasticity of the polishing pad leads to improved flatness and increased polishing scratches. Conversely, decreased elasticity of the polishing pad leads to decreased polishing scratches and degraded flatness. Regarding polishing scratches, however, there is a strong correlation with elasticity particularly near the surface of the polishing pad.

To improve this trade-off, a polishing pad containing water-soluble particles is developed. According to this technology, a state of high elasticity in an inner portion of the polishing pad that is not exposed to water and low elasticity in a surface portion that is exposed to water is realized. However, the surface portion of the polishing pad always has low elasticity during polishing of an object to be polished according to this technology, which is not sufficient for a device requiring an ultrahigh level of flatness.

Also, a technology to control elasticity of a whole polishing pad during a CMP process by installing piping for cooling the polishing pad inside the polishing pad or on the back side of the polishing pad to control the temperature of the entire polishing pad is developed. However, it is not possible to control elasticity of only the surface portion of the polishing pad according to this technology, which is not sufficient for the above trade-off.

Thus, the embodiment proposes a polishing pad containing water-soluble particles whose solubility is controlled and a CMP apparatus including a mechanism capable of controlling the temperature of the polishing pad.

That is, a CMP apparatus in the embodiment includes together with a polishing pad containing water-soluble particles as a pair. Moreover, a temperature setting portion to set the temperature of the surface portion of the polishing pad is provided in the surface portion of the polishing pad. Then, polishing of an object to be polished is performed while the
temperature of the surface portion of the polishing pad is set to within a first temperature range and then, polishing of the object to be polished is performed while the temperature of the surface portion of the polishing pad is set to within a second temperature range.

Accordingly, the polishing pad containing water-soluble particles is in two states during polishing of the object to be polished. The first state arises when the temperature of the surface portion of the polishing pad is within the first temperature range and is a state in which elasticity of the entire polishing pad is high. The second state arises when the temperature of the surface portion of the polishing pad is within the second temperature range and is a state in which elasticity of the surface portion of the polishing pad is low and elasticity of portions other than the surface portion is high.

In the first state, the solubility of water-soluble particles exposed to the surface portion of the polishing pad is reduced to 0% or a low state and thus, elasticity of the entire polishing pad is high. Therefore, polishing with importance placed on ensuring a high level of flatness is performed on the object to be polished.

In the first state, the solubility of water-soluble particles exposed to the surface portion of the polishing pad is desirably 10% or less from the viewpoint of ensuring a high level of flatness.

In the second state, the solubility of water-soluble particles exposed to the surface portion of the polishing pad is high and thus, elasticity of the surface portion of the polishing pad is low. In portions other than the surface portion, elasticity is high because water-soluble particles are not exposed and are not dissolved. Therefore, polishing with importance placed on the reduction of polishing scratches on the object to be polished is performed.

The second state is realized by controlling elasticity of only the surface portion of the polishing pad and thus, elasticity of portions other than the surface portion of the polishing pad remains high and flatness is not degraded by the polishing.

By causing these two states during polishing of the object to be polished, it becomes possible to ensure a high level of flatness and reduce polishing scratches at the same time.

The solubility of water-soluble particles exposed to the surface portion of the polishing pad can be controlled by, in addition to the temperature of the surface portion of the polishing pad, causing slurry (for example, containing polishing particles and water) supplied to the surface portion of the polishing pad to contain a substance that is the same as water-soluble particles or has the same property as water-soluble particles in advance.

FIGS. 1 and 2 show a CMP apparatus as an embodiment.

FIG. 1 is a perspective view of a CMP apparatus and FIG. 2 is a side view of the CMP apparatus in FIG. 1.

Stage portion (for example, rotating table) 11 is, for example, driven to rotate (clockwise/counterclockwise). Polishing pad 12 containing water-soluble particles is mounted on stage portion 11.

Polishing pad 12 is configured by, for example, as shown in FIG. 3, water-insoluble crosslinked polymer 12a. Crosslinked polymer 12a is a foam and is filled with water-soluble particles 12b. Such polishing pad 12 is called a filler pad.

A crosslinked polymer is polyurethane, polystyrene or the like and water-soluble particles are a polysaccaride such as dextrin, cellulose containing an aliphatic chain or the like.

Holding portion 13 holds object to be polished 14 and brings object to be polished 14 into contact with the surface portion of polishing pad 12 while holding object to be polished 14. Holding portion 13 is, for example, driven to rotate (clockwise/counterclockwise).

Stage portion 11 and holding portion 13 are desirably driven to rotate together from the viewpoint of eliminating unevenness of the polishing amount of object to be polished 14. When both are driven to rotate, the rotation direction of holding portion 13 and the rotation direction of stage portion 11 are desirably the same.

Object to be polished 14 is, for example, as shown in FIG. 4, a semiconductor device. Here, a semiconductor device including semiconductor substrate 14a, stopper film 14b on semiconductor substrate 14a, and dielectric film 14c embedded in a groove of semiconductor substrate 14a is shown as an example of object to be polished 14.

In FIG. 4, stopper film 14b is formed of a material having etching selectivity to dielectric film 14c. If, for example, dielectric film 14c is a silicon oxide film, stopper film 14b is a silicon nitride film.

Supplying portion 15 is arranged above stage portion 11 and, if stage portion 11 is, for example, cylindrical, above the center portion of a circle to supply slurry to the surface portion of polishing pad 12. The slurry contains, for example, a chemical solution such as a polishing agent, water and the like.

By causing the slurry to contain a substance that is the same as water-soluble particles or has the same property as water-soluble particles in advance, the solubility of water-soluble particles exposed to the surface portion of polishing pad 12 can be controlled. Being able to control the solubility of water-soluble particles means also increasing choices of water-soluble particles.

Further, if a polysaccharide such as dextrin is used as water-soluble particles, the solubility thereof into the slurry can be adjusted by adjusting the molecular weight thereof.

Surface conditioning portion 16 has a function to, by polishing object to be polished 14, return the surface portion of polishing pad 12 worn out or clogged by abrasive grains contained in the polishing agent or the like to the initial state of object to be polished 14 before polishing.

In the present example, water-soluble particles exposed to the surface portion of polishing pad 12 are dissolved by one CMP step on object to be polished 14 and thus, surface conditioning portion 16 returns the surface portion of polishing pad 12 to the initial state each time the one CMP step ends.

Surface conditioning portion 16 returns the surface portion of polishing pad 12 to the initial state by cutting a fixed amount of the surface portion of polishing pad 12 to expose new water-soluble particles to the surface portion of polishing pad 12.

Temperature setting portion 17 is arranged in the surface portion of polishing pad 12 to set the temperature of the surface portion of polishing pad 12. Temperature setting portion 17 includes, for example, a heat exchanger (contact mechanism) that comes into contact with the surface portion
of polishing pad 12 and a non-contact mechanism that supplies an inert gas (heat-exchanger gas) to the surface portion of polishing pad 12.

[0054] If temperature setting portion 17 is configured by a heat exchanger, the controllable temperature range of the surface portion of the polishing pad can be ensured widely, increasing choices of the type of polishing pad (water-soluble particles) 12. If temperature setting portion 17 is configured by a non-contact mechanism, scratches and non-uniformity will not be caused in polishing pad 12 and, as a result, polishing scratches of object to be polished 14 can further be reduced.

[0055] Temperature setting portion 17 may further include a temperature sensor. Alternatively, temperature setting portion 17 may not include a temperature sensor by providing the temperature sensor in a portion other than temperature setting portion 17.

[0056] Control portion 18 controls operations of stage portion 11, holding portion 13, supplying portion 15, surface conditioning portion 16, and temperature setting portion 17. Control portion 18 sets the temperature of the surface portion of polishing pad 12 through temperature setting portion 17 based on a dissolved threshold value at which water-soluble particles exposed to the surface portion inside polishing pad 12 can completely be dissolved.

[0057] If the temperature of the surface portion of the polishing pad is set to the dissolved threshold value or higher under the assumption that water-soluble particles can dissolve into slurry without limitation, the solubility of water-soluble particles exposed to the surface portion in polishing pad 12 becomes 100%.

[0058] However, if the slurry contains a substance that is the same as water-soluble particles or has the same property as water-soluble particles in advance, a saturated state may be reached before water-soluble particles are completely dissolved so that the solubility of water-soluble particles exposed to the surface portion in polishing pad 12 may be less than 100% even if the temperature of the surface portion inside polishing pad 12 is equal to or higher than the dissolved threshold value.

[0059] Control portion 18 includes management table 19 to set the temperature of the surface portion of polishing pad 12 through temperature setting portion 17 based on the dissolved threshold value.

[0060] Management table 19 includes, for example, as shown in FIG. 5, information about the slurry, polishing pad, and dissolved threshold value of water-soluble particles and control portion 18 is caused to store management table 19 therein in advance. For example, the slurry and polishing pad are freely exchangeable and thus, input information about the slurry and polishing pad is input into control portion 18 before driving a CMP apparatus in the present example.

[0061] Based on the input information, control portion 18 recognizes the dissolved threshold value to realize the above two states during polishing of object to be polished 14.

[0062] Management table 19 is only an example and if, for example, one of the slurry and polishing pad is fixed, only unfixed information may be input to decide the dissolved threshold value. Alternatively, the dissolved threshold value of water-soluble particles may directly be input into control portion 18 without providing management table 19.

[0063] Control portion 18 also includes torque current monitor portion 20.

[0064] Torque current monitor portion 20 is provided to decide a switching point of a first polishing step in the first state in which entire polishing pad 12 has high elasticity, a second polishing step in the second state in which only the surface portion of polishing pad 12 has low elasticity, and further a surface conditioning step of polishing pad 12 in which the surface portion of polishing pad 12 is returned to the initial state.

[0065] That is, when stage portion 11 and holding portion 13 are each driven at a fixed rotation speed, the switching point can be decided by monitoring a torque current value to drive stage portion 11 and holding portion 13 to rotate.

[0066] If object to be polished 14 is, for example, a semiconductor device shown in FIG. 4, the above first polishing step can be executed while irregularities of dielectric film 14c are present and the above second polishing step can be executed while irregularities of dielectric film 14c are eliminated.

[0067] This is because, for example, as shown in FIG. 6, the torque current value increases due to contact resistance between polishing pad 12 and object to be polished 14 with decreasing irregularities of dielectric film 14c and after irregularities of dielectric film 14c are eliminated, the torque current value becomes constant at the maximum value. Therefore, the first polishing step can be switched to the second polishing step by detecting change point (first change point) P1 of the torque current value.

[0068] The above second polishing step can be executed while irregularities of dielectric film 14c are eliminated and the CMP step can be finished to execute the above surface conditioning step while stopper film 14b is exposed.

[0069] This is because the contact resistance between polishing pad 12 and dielectric film 14c and the contact resistance between polishing pad 12 and stopper film 14b are different. Therefore, for example, as shown in FIG. 6, the second polishing step can be switched to the surface conditioning step by detecting change point (second change point) P2 of the torque current value.

[0070] To detect change points P1, P2 of the torque current value, for example, a fixed judgment term is necessary and thus, it is desirable to switch each step after this judgment term.

[0071] Installation of torque current monitor portion 20 is desirable to switch the first polishing step, second polishing step, and surface conditioning step correctly.

[0072] However, these steps can be switched without providing torque current monitor portion 20. For example, the first polishing step, second polishing step, and surface conditioning step may be switched by monitoring the polishing time in the CMP step according to a rule of thumb.

[0073] FIG. 7 shows a first example of the CMP method.

[0074] This flowchart is executed by control portion 18 in FIG. 1.

[0075] Water-soluble particles in the polishing pad are a substance whose solubility into slurry increases with a rising temperature within the temperature range of the surface portion of the polishing pad set by the temperature setting portion.

[0076] It is assumed that dissolved threshold value (temperature) Tc1 of water-soluble particles is within the temperature range thereof and water-soluble particles exposed to the surface portion of the polishing pad can completely dissolve
into slurry when the temperature of the surface portion inside the polishing pad is equal to or higher than dissolved threshold value Tc1.

[0077] Under the above assumption, for example, as shown in FIG. 8, the temperature of the surface portion of the polishing pad is changed. That is, in the first polishing step, the temperature of the surface portion of the polishing pad is made sufficiently lower than dissolved threshold value Tc1. In the second polishing step, the temperature of the surface portion of the polishing pad is made equal to or higher than dissolved threshold value Tc1. Further, in the surface conditioning step of the polishing pad, the temperature of the surface portion of the polishing pad is made sufficiently lower than dissolved threshold value Tc1 again.

[0078] Concrete operations will be described below based on the flowchart in FIG. 7 and side views in FIGS. 9 to 15.

[0079] First, dissolved threshold value Tc1 is set to a register in the control portion based on input information (for example, the slurry, polishing pad and so on) (step ST1).

[0080] After, as shown in FIG. 9, stage portion 11 on which polishing pad 12 is mounted is rotated, slurry is supplied onto polishing pad 12 from supplying portion 15. The slurry is spread over entire polishing pad 12 due to a centrifugal force.

[0081] Subsequently, temperature Tsurface of the surface portion of polishing pad 12 is set to the first temperature range (less than dissolved threshold value Tc1) (step ST2).

[0082] Then, as shown in FIG. 10, object to be polished 14 held by holding portion 13 is brought into contact with polishing pad 12 to execute the first polishing step to polish object to be polished 14 while temperature Tsurface of the surface portion of polishing pad 12 is maintained within the first temperature range. At this point, like stage portion 11, holding portion 13 may also be rotated.

[0083] In the first polishing step, temperature Tsurface of the surface portion of polishing pad 12 is set to within the first temperature range and thus, the solubility of water-soluble particles exposed to the surface portion of polishing pad 12 into slurry is 0% or a low state (desirably 10% or less).

[0084] Therefore, elasticity of entire polishing pad 12 is maintained high and polishing with importance placed on maintenance of a high level of flatness is performed. Also, as shown in FIG. 13, a protrusion of dielectric film 14c of object to be polished 14 mainly comes into contact with polishing pad 12 to be preferentially polished. Therefore, when the first polishing step proceeds to some extent, irregularities of dielectric film 14c of object to be polished 14 are eliminated.

[0085] Then, after, as shown in FIG. 14, the surface of dielectric film 14c of object to be polished 14 is planarized, a contact area (contact resistance) between polishing pad 12 and object to be polished 14 increases, causing a change of the torque current value (first change point P1 in FIG. 6).

[0086] The torque current monitor portion monitors torque current value Torque during a CMP step and after passing through change point (first change point) P1, switches the first polishing step to the second polishing step (step ST3).

[0087] That is, the torque current monitor portion sets temperature Tsurface of the surface portion of polishing pad 12 to the second temperature range (dissolved threshold value Tc1 or higher) (step ST4).

[0088] Then, as shown in FIG. 11, the second polishing step to polish object to be polished 14 is subsequently executed while temperature Tsurface of the surface portion of polishing pad 12 is maintained within the second temperature range.

[0089] In the second polishing step, temperature Tsurface of the surface portion of polishing pad 12 is set to within the second temperature range and thus, the solubility of water-soluble particles exposed to the surface portion of polishing pad 12 into slurry is high (100% or close thereto).

[0090] The solubility of water-soluble particles in the second polishing step has only to be higher than that of water-soluble particles in the first polishing step. That is, it is desirable to adjust the solubility of water-soluble particles in the second polishing step in accordance with the type of object to be polished 14.

[0091] Therefore, elasticity of the surface portion of polishing pad 12 is maintained low and polishing with importance placed on the reduction of polishing scratches is performed. Elasticity of portions other than the surface portion of polishing pad 12 remains high and a high level of flatness is not degraded by the second polishing step.

[0092] The second polishing step is desirably as short as possible on condition that the amount and size of polishing scratches are within permissible ranges.

[0093] As shown in FIG. 15, when the second polishing step proceeds to some extent, the surface of stopper film 14b of object to be polished 14 is exposed.

[0094] If the surface of stopper film 14b of object to be polished 14 is exposed, the contact resistance between polishing pad 12 and object to be polished 14 changes and thus, a change in torque current value also appears (second change point P2 in FIG. 6).

[0095] The torque current monitor portion monitors torque current value Torque during a CMP step and after passing through change point (second change point) P2, terminates the second polishing step (step ST5).

[0096] Then, as shown in FIG. 12, holding portion 13 is raised to move object to be polished 14 away from polishing pad 12. Also, the surface conditioning step to return the surface portion of polishing pad 12 to the initial state is executed while temperature Tsurface of the surface portion of polishing pad 12 is maintained within the first temperature range (less than dissolved threshold value Tc1).

[0097] That is, while temperature Tsurface of the surface portion of polishing pad 12 is set to within the first temperature range (step ST6), surface conditioning portion 16 is lowered and the surface portion of polishing pad 12 is cut by surface conditioning portion 16 to newly expose water-soluble particles to the surface portion of polishing pad 12 (step ST7).

[0098] The temperature of polishing pad 12 does not change markedly in the surface conditioning step, but it is necessary to pay close attention to the temperature of polishing pad 12 so that the temperature does not rise to Tc1 or higher.

[0099] According to the present example (embodiment), as shown in FIG. 16, elasticity of polishing pad 12 changes during a CMP step. Moreover, the first state in which elasticity of entire polishing pad 12 is high is maintained in the first polishing step and the second state in which elasticity of only the surface portion of polishing pad 12 is lowered from the first state is maintained in the second polishing step.

[0100] Therefore, according to the embodiment, compared with Comparative Example 1 in which elasticity is constant during CMP step and Comparative Example 2 in which elasticity of the entire polishing pad changes during CMP step, both of ensuring a high level of flatness and the reduction of polishing scratches can be improved.
FIG. 17 shows a second example of the CMP method.

This flowchart is executed by control portion 18 in FIG. 1.

Water-soluble particles in the polishing pad are a substance whose solubility into slurry increases with a falling temperature within the temperature range of the surface portion of the polishing pad set by the temperature setting portion.

It is assumed that dissolved threshold value (temperature) \( T_{c2} \) of water-soluble particles is within the temperature range thereof and water-soluble particles exposed to the surface portion of the polishing pad can completely dissolve into slurry when the temperature of the surface portion inside the polishing pad is equal to or lower than dissolved threshold value \( T_{c2} \).

Under the above assumption, for example, as shown in FIG. 18, the temperature of the surface portion of the polishing pad is changed. That is, in the first polishing step, the temperature of the surface portion of the polishing pad is made sufficiently higher than dissolved threshold value \( T_{c2} \).

In the second polishing step, the temperature of the surface portion of the polishing pad is made equal to or lower than dissolved threshold value \( T_{c2} \). Further, in the surface conditioning step of the polishing pad, the temperature of the surface portion of the polishing pad is made sufficiently higher than dissolved threshold value \( T_{c2} \) again.

Concrete operations will be described below based on the flowchart in FIG. 17 and side views in FIGS. 19 to 22.

First, dissolved threshold value \( T_{c2} \) is set to a register in the control portion based on input information (for example, the slurry, polishing pad and so on) (step ST1).

After, as shown in FIG. 19, stage portion 11 on which polishing pad 12 is mounted is rotated, slurry is supplied onto polishing pad 12 from supplying portion 15. The slurry is spread over entire polishing pad 12 due to a centrifugal force.

Subsequently, temperature \( T_{s} \) of the surface portion of polishing pad 12 is set to the first temperature range (exceeding dissolved threshold value \( T_{c2} \)) (step ST2).

Then, as shown in FIG. 20, object to be polished 14 held by holding portion 13 is brought into contact with polishing pad 12 to execute the first polishing step to polish object to be polished 14 while temperature \( T_{s} \) of the surface portion of polishing pad 12 is maintained within the first temperature range. At this point, like stage portion 11, holding portion 13 may also be rotated.

In the first polishing step, temperature \( T_{s} \) of the surface portion of polishing pad 12 is set to within the first temperature range and thus, the solubility of water-soluble particles exposed to the surface portion of polishing pad 12 into slurry is 0%, or low (desirably 10% or less).

Therefore, elasticity of entire polishing pad 12 is maintained high and polishing with importance placed on maintenance of a high level of flatness is performed. Also, as shown in FIG. 13, a protrusion of dielectric film 14c of object to be polished 14 mainly comes into contact with polishing pad 12 to be preferentially polished. Therefore, when the first polishing step proceeds to some extent, irregularities of dielectric film 14c of object to be polished 14 are eliminated.

Then, after, as shown in FIG. 14, the surface of dielectric film 14c of object to be polished 14 is planarized, a contact area (contact resistance) between polishing pad 12 and object to be polished 14 increases, causing a change of the torque current value (first change point P1 in FIG. 6).

The torque current monitor portion monitors torque current value \( I_{t} \) during CMP step and after passing through change point (first change point) \( P1 \), switches the first polishing step to the second polishing step (step ST3).

That is, temperature \( T_{s} \) of the surface portion of polishing pad 12 is set to the second temperature range (dissolved threshold value \( T_{c2} \) or lower) (step ST4).

Then, as shown in FIG. 21, the second polishing step to polish object to be polished 14 is subsequently executed while temperature \( T_{s} \) of the surface portion of polishing pad 12 is maintained within the second temperature range.

In the second polishing step, temperature \( T_{s} \) of the surface portion of polishing pad 12 is set to within the second temperature range and thus, the solubility of water-soluble particles exposed to the surface portion of polishing pad 12 into slurry is high (100% or close thereto).

The solubility of water-soluble particles in the second polishing step has only to be higher than that of water-soluble particles in the first polishing step. That is, it is desirable to adjust the solubility of water-soluble particles in the second polishing step in accordance with the type of object to be polished 14.

Therefore, elasticity of the surface portion of polishing pad 12 is maintained low and polishing with importance placed on the reduction of polishing scratches is performed. Elasticity of other portions than the surface portion of polishing pad 12 remains high and a high level of flatness is not degraded by the second polishing step.

The second polishing step is desirably as short as possible on condition that the amount and size of scratches are within permissible ranges.

As shown in FIG. 15, when the second polishing step proceeds to some extent, the surface of stopper film 14b of object to be polished 14 is exposed.

If the surface of stopper film 14b of object to be polished 14 is exposed, the contact resistance between polishing pad 12 and object to be polished 14 changes and thus, a change in torque current value also appears (second change point P2 in FIG. 6).

The torque current monitor portion monitors torque current value \( I_{t} \) during CMP step and after passing through change point (second change point) \( P2 \), terminates the second polishing step (step ST5).

Then, as shown in FIG. 22, holding portion 13 is raised to move object to be polished 14 away from polishing pad 12. Also, the surface conditioning step to return the surface portion of polishing pad 12 to the initial state is executed while temperature \( T_{s} \) of the surface portion of polishing pad 12 is maintained within the first temperature range (exceeding dissolved threshold value \( T_{c2} \)).

That is, while temperature \( T_{s} \) of the surface portion of polishing pad 12 is set to within the first temperature range (step ST6), surface conditioning portion 16 is lowered and the surface portion of polishing pad 12 is cut by surface conditioning portion 16 to newly expose water-soluble particles to the surface portion of polishing pad 12 (step ST7).

The temperature of polishing pad 12 does not change markedly in the surface conditioning step, but it is necessary to pay close attention to the temperature of polishing pad 12 so that the temperature does not fall to \( T_{c2} \) or lower.
According to the present example (embodiment), as shown in FIG. 16, elasticity of polishing pad 12 changes during a CMP step. Moreover, the first state in which elasticity of entire polishing pad 12 is high is maintained in the first polishing step and the second state in which elasticity of only the surface portion of polishing pad 12 is lowered from the first state is maintained in the second polishing step. Therefore, according to the embodiment, compared with Comparative Example 1 in which elasticity is constant during a CMP step and Comparative Example 2 in which elasticity of the entire polishing pad changes during a CMP step, both of ensuring a high level of flatness and the reduction of polishing scratches can be improved.

FIG. 23 shows a modification of the CMP apparatus in FIG. 1.

This modification is different from the CMP apparatus in FIG. 1 in that temperature setting portion 21 includes only a cooling mechanism and omits a heating mechanism.

This is because frictional heat is generated between polishing pad 12 and object to be polished 14 during CMP step. The temperature of polishing pad 12 gradually rises due to frictional heat without being heated by temperature setting portion 21. By using this frictional heat, the heating mechanism can be omitted to simplify the configuration of temperature setting portion 21.

The cooling mechanism includes, for example, a heat exchanger (contact mechanism) that comes into contact with the surface portion of polishing pad 12 and a non-contact mechanism that supplies an inert gas (heat-exchanger gas) to the surface portion of polishing pad 12. If the cooling mechanism is configured by a non-contact mechanism, scratches and non-uniformity will not be caused in polishing pad 12 and, as a result, polishing scratches of object to be polished 14 can further be reduced.

However, if this example is adopted, it is necessary to verify how frictional heat generated between polishing pad 12 and object to be polished 14 changes during a CMP step in advance.

That is, the necessary condition is that before executing the second polishing step, the temperature of the surface portion of polishing pad 12 is the dissolved threshold value or higher.

Other structural elements are the same as those of the CMP apparatus in FIG. 1 and a detailed description thereof is omitted.

FIG. 24 shows a third example of the CMP method.

This flowchart is executed by control portion 18 in FIG. 23.

Water-soluble particles in the polishing pad are a substance whose solubility into slurry increases with a rising temperature within the temperature range of the surface portion of the polishing pad set by the temperature setting portion.

It is assumed that dissolved threshold value (temperature) TC3 of water-soluble particles is within the temperature range thereof and water-soluble particles exposed to the surface portion of the polishing pad can completely dissolve into slurry when the temperature of the surface portion inside the polishing pad is equal to or higher than dissolved threshold value TC3.

Under the above assumption, the temperature of the surface portion of the polishing pad changes, for example, as shown in FIG. 25, linearly due to frictional heat between the polishing pad and the object to be polished.

That is, the temperature of the surface portion of the polishing pad gradually rises in the first polishing step due to frictional heat, but does not reach dissolved threshold value TC3.

In the second polishing step, the temperature of the surface portion of the polishing pad is maintained at dissolved threshold value TC3 or higher due to frictional heat. However, it is desirable to control the temperature of the surface portion of the polishing pad so that the temperature is stabilized to a certain value equal to or higher than dissolved threshold value TC3 to avoid too high a temperature by frictional heat and cooling by the temperature setting portion.

Further, in the surface conditioning step of the polishing pad, the temperature of the surface portion of the polishing pad is set to less than dissolved threshold value TC3 by cooling of the temperature setting portion.

Concrete operations will be described below based on the flowchart in FIG. 24 and side views in FIGS. 26 to 29.

First, dissolved threshold value TC3 is set to a register in the control portion based on input information (for example, the slurry, polishing pad and so on) (step ST1).

After, as shown in FIG. 26, stage portion 11 on which polishing pad 12 is mounted is rotated, slurry is supplied onto polishing pad 12 from supplying portion 15. The slurry is spread over entire polishing pad 12 due to a centrifugal force.

At this point, temperature (initial value) Tsurface of the surface portion of polishing pad 12 is assumed to be within the first temperature range (less than dissolved threshold value TC3).

Subsequently, as shown in FIG. 27, object to be polished 14 held by holding portion 13 is brought into contact with polishing pad 12 to execute the first polishing step to polish object to be polished 14. At this point, like stage portion 11, holding portion 13 may also be rotated.

In the first polishing step, temperature Tsurface of the surface portion of polishing pad 12 gradually rises due to frictional heat. However, temperature Tsurface will not reach dissolved threshold value TC3 or higher if the relationship between the time and temperature rise rate is controlled by the cooling mechanism of the temperature setting portion (step S12).

Therefore, the solubility of water-soluble particles exposed to the surface portion of polishing pad 12 into slurry is 0% or low (desirably 10% or less).

Therefore, elasticity of entire polishing pad 12 is maintained high and polishing with importance placed on maintenance of a high level of flatness is performed. Also, as shown in FIG. 13, a protrusion of dielectric film 14c of object to be polished 14 mainly comes into contact with polishing pad 12 to be preferentially polished. Therefore, when the first polishing step proceeds to some extent, irregularities of dielectric film 14c of object to be polished 14 are eliminated.

Loop, then, as shown in FIG. 14, the surface of dielectric film 14c of object to be polished 14 is planarized, a contact area (contact resistance) between polishing pad 12 and object to be polished 14 increases, causing a change of the torque current value (first change point P1 in FIG. 6).

The torque current monitor portion monitors torque current value ltorque during a CMP step and after passing through change point (first change point) P1, switches the first polishing step to the second polishing step (step ST3).

That is, temperature Tsurface of the surface portion of polishing pad 12 is set to the second temperature range
(dissolved threshold value $T_{c3}$) by increasing the temperature rise rate of the surface portion of polishing pad 12 at a stroke through frictional heat by weakening the cooling mechanism or making the cooling mechanism inoperable (step ST4).

[0155] Then, as shown in FIG. 28, the second polishing step to polish object to be polished 14 is subsequently executed while temperature $T_{surface}$ of the surface portion of polishing pad 12 is maintained within the second temperature range by frictional heat and the cooling mechanism.

[0156] In the second polishing step, temperature $T_{surface}$ of the surface portion of polishing pad 12 is set to within the second temperature range and thus, the solubility of water-soluble particles exposed to the surface portion of polishing pad 12 into slurry is high (100% or close thereto).

[0157] The solubility of water-soluble particles in the second polishing step has only to be higher than that of water-soluble particles in the first polishing step. That is, it is desirable to adjust the solubility of water-soluble particles in the second polishing step in accordance with the type of object to be polished 14.

[0158] Therefore, elasticity of the surface portion of polishing pad 12 is maintained low and polishing with importance placed on the reduction of polishing scratches is performed. Elasticity of other portions than the surface portion of polishing pad 12 remains high and a high level of flatness is not degraded by the second polishing step.

[0159] The second polishing step is desirably as short as possible on condition that the amount and size of scratches are within permissible ranges.

[0160] As shown in FIG. 15, when the second polishing step proceeds to some extent, the surface of stopper film 14b of object to be polished 14 is exposed.

[0161] If the surface of stopper film 14b of object to be polished 14 is exposed, the contact resistance between polishing pad 12 and object to be polished 14 changes and thus, a change in torque current value also appears (second change point P2 in FIG. 6).

[0162] The torque current monitor portion monitors torque current value torque during a CMP step and after passing through change point (second change point) P2, terminates the second polishing step (step ST5).

[0163] Then, as shown in FIG. 29, holding portion 13 is raised to move object to be polished 14 away from polishing pad 12. Also, the surrounding conditioning step to return the surface portion of polishing pad 12 to the initial state is executed while temperature $T_{surface}$ of the surface portion of polishing pad 12 is set to within the first temperature range (less than dissolved threshold value $T_{c3}$) by the cooling mechanism.

[0164] That is, while temperature $T_{surface}$ of the surface portion of polishing pad 12 is maintained within the first temperature range (step ST6), surface conditioning portion 16 is lowered and the surface portion of polishing pad 12 is cut by surface conditioning portion 16 to newly expose water-soluble particles to the surface portion of polishing pad 12 (step ST7).

[0165] The temperature of polishing pad 12 does not change markedly in the surface conditioning step, but it is necessary to pay close attention to the temperature of polishing pad 12 so that the temperature does not rise to $T_{c3}$ or higher.

[0166] According to the present example (embodiment), as shown in FIG. 16, elasticity of polishing pad 12 changes during a CMP step. Moreover, the first state in which elasticity of entire polishing pad 12 is high is maintained in the first polishing step and the second state in which elasticity of only the surface portion of polishing pad 12 is lowered from the first state is maintained in the second polishing step.

[0167] Therefore, according to the embodiment, compared with Comparative Example 1 in which elasticity is constant during a CMP step and Comparative Example 2 in which elasticity of the entire polishing pad changes during a CMP step, both of ensuring a high level of flatness and the reduction of polishing scratches can be improved.

[0168] According to the embodiment, a CMP technology capable of ensuring a high level of flatness and reducing polishing scratches can be provided. Therefore, highly reliable semiconductor devices can be manufactured by applying the technology to manufacturing processes of next-generation devices of the 32-nm generation or thereafter or devices of novel structures having a wide space.

Next-Generation Devices

[0169] Next-generation devices such as a resistance changing memory (for example, a resistive random access memory: ReRAM) attempt to increase the memory capacity by making a memory cell array three-dimensional. To realize such a memory cell array (three-dimensional cross-point type) of next-generation devices, a CMP technology that ensures a high level of flatness and reduces polishing scratches at the same time is indispensable. Therefore, application of the embodiment makes next-generation devices realizable.

Devices of Novel Structures

[0170] In recent years, many devices having novel structures that are micropatterned and multi-layered have been developed. By applying the CMP technology in the embodiment to such devices, a highly reliable semiconductor device can be realized. In a device of a novel structure, for example, it is difficult to impose constraints according to conventional design rules and ensuring a high level of flatness of dielectric films embedded in a wide space is also important along with embedding of fine spaces. Therefore, application of the embodiment makes such devices of novel structures realizable.

[0171] While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

What is claimed is:

1. A CMP apparatus comprising:
   a supplying portion supplying a slurry to a surface portion of a polishing pad including water-soluble particles;
   a holding portion contacting an object to be polished with the surface portion of the polishing pad in a condition of holding the object;
   a temperature setting portion on the surface portion of the polishing pad, the temperature setting portion setting a temperature of the surface of the polishing pad; and
a control portion controlling an operation of the supplying portion, the holding portion and the temperature setting portion, wherein the control portion executes a first polishing step and a second polishing step after the first polishing step, the object is polished in a condition of setting the temperature of the surface of the polishing pad within a first temperature range in the first polishing step, and the object is polished in a condition of setting the temperature of the surface of the polishing pad within a second temperature range in the second polishing step.

2. The apparatus of claim 1, wherein the control portion controls an operation of the temperature setting portion based on a dissolved threshold value at which the water-soluble particles completely dissolve into the slurry.

3. The apparatus of claim 1, wherein a solubility of the water-soluble particles exposed to the surface portion of the polishing pad in the second polishing step is higher than the solubility of the water-soluble particles exposed to the surface portion of the polishing pad in the first polishing step.

4. The apparatus of claim 3, wherein the solubility of the water-soluble particles is controlled by causing the slurry supplied to the surface portion of the polishing pad from the supplying portion to contain a substance that is the same as the water-soluble particles or has the same property as the water-soluble particles in advance.

5. The apparatus of claim 1, further comprising a stage portion on which the polishing pad is mounted, wherein the holding portion and the stage portion are driven to rotate, and the control portion monitors a torque current value used to drive the holding portion or the stage portion to rotate and changes the first polishing step to the second polishing step after the torque current value is judged to have passed through a first change point.

6. The apparatus of claim 5, further comprising a surface conditioning portion that conditions a state of the surface portion of the polishing pad, wherein the control portion terminates the second polishing step after the torque current value is judged to have passed through a second change point and executes a surface conditioning step for returning the surface portion of the polishing pad to an initial state by the surface conditioning portion after the temperature of the surface portion of the polishing pad is changed from within the second temperature range to within the first temperature range.

7. The apparatus of claim 1, wherein the temperature setting portion includes a heat exchanger in contact with the surface portion of the polishing pad.

8. The apparatus of claim 1, wherein the temperature setting portion includes a mechanism that supplies an inert gas to the surface portion of the polishing pad.

9. The apparatus of claim 1, wherein the temperature setting portion includes a mechanism to cool the surface portion of the polishing pad and the temperature of the surface portion of the polishing pad is controlled by frictional heat between the polishing pad and the object to be polished and the mechanism.

10. The apparatus of claim 9, wherein the temperature of the surface portion of the polishing pad changes linearly.

11. The apparatus of claim 1, wherein the water-soluble particles are dextrin or cellulose containing an aliphatic chain.

12. A polishing pad using the apparatus of claim 1, comprising:

   a water-insoluble crosslinked polymer; and

   water-soluble particles in the crosslinked polymer,

wherein a solubility of the water-soluble particles changes during polishing of an object to be polished.

13. A CMP method comprising:

   supplying slurry to a surface portion of a polishing pad including water-soluble particles;

   bringing an object to be polished into contact with the surface portion of the polishing pad; and

   executing a first polishing step and a second polishing step after the first polishing step, the object being polished in a condition of setting the temperature of the surface portion of the polishing pad within a first temperature range in the first polishing step, and the object being polished in a condition of setting the temperature of the surface portion of the polishing pad within a second temperature range in the second polishing step.

14. The method of claim 13, wherein a solubility of the water-soluble particles exposed to the surface portion of the polishing pad in the second polishing step is higher than a solubility of the water-soluble particles exposed to the surface portion of the polishing pad in the first polishing step.

15. The method of claim 13, wherein a solubility of the water-soluble particles is controlled by causing the slurry supplied to the surface portion of the polishing pad from the supplying portion to contain a substance that is the same as the water-soluble particles or has the same property as the water-soluble particles in advance.

16. The method of claim 13, wherein the object to be polished and the polishing pad are driven to rotate, and a torque current value at which the object to be polished or the polishing pad is driven to rotate is monitored and the first polishing step is changed to the second polishing step after the torque current value is judged to have passed through a first change point.

17. The method of claim 16, wherein polishing of the object to be polished is terminated after the torque current value is judged to have passed through a second change point, and the surface portion of the polishing pad is returned to an initial state after the temperature of the surface portion of the polishing pad is changed from within the second temperature range to within the first temperature range.

18. The method of claim 13, wherein the temperature of the surface portion of the polishing pad is set by a heat exchanger in contact with the surface portion of the polishing pad.

19. The method of claim 13, wherein the temperature of the surface portion of the polishing pad is set by a mechanism that supplies an inert gas to the surface portion of the polishing pad.

20. The method of claim 13, wherein the temperature of the surface portion of the polishing pad is set by frictional heat between the polishing pad and the object to be polished and a mechanism to cool the surface portion of the polishing pad.