

POLISHING APPARATUS AND POLISHING METHOD

BACKGROUND OF THE INVENTION

Field of the Invention:

5 The present invention relates to a polishing apparatus and a polishing method for polishing a surface of a substrate, such as a wafer, by rubbing the substrate against a polishing pad, and more particularly to a polishing apparatus and a polishing method for polishing the surface of the substrate while measuring, from below the substrate, frictional heat generated as a result of the sliding contact between the substrate and the
10 polishing pad.

Description of the Related Art:

Chemical mechanical polishing (CMP) is known as a technique to polish a substrate, such as a wafer. FIG. 16 is a perspective view showing a conventional polishing apparatus for polishing a wafer chemically and mechanically. As shown in
15 FIG. 16, the polishing apparatus generally includes a polishing table 103 supporting a polishing pad 102, a polishing head 101 for pressing a wafer W against the polishing pad 102, and a polishing liquid supply nozzle 105 for supplying a polishing liquid (e.g., slurry or pure water) onto the polishing pad 102. The polishing pad 102 has a surface that constitutes a polishing surface 102a for polishing the wafer W.

20 The wafer W is polished in the following manner. While the polishing table 103 and the polishing head 101 are rotated in directions indicated by arrows shown in FIG. 16, the polishing liquid is supplied from the polishing liquid supply nozzle 105 onto the polishing surface 102a of the polishing pad 102 on the polishing table 103. The wafer W is rotated by the polishing head 101, while the wafer W is pressed against the polishing
25 surface 102a of the polishing pad 102 in the presence of the polishing liquid between the polishing pad 102 and the wafer W. The surface of the wafer W is polished by a mechanical action of abrasive particles contained in the polishing liquid and by a chemical action of the polishing liquid.

As described above, the surface of the wafer W is polished with the sliding contact between the polishing pad 102 and the wafer W. The sliding contact between the polishing pad 102 and the wafer W generates frictional heat. The frictional heat depends on a material and a shape of an exposed surface of the wafer W, and a
5 temperature of the polishing surface 102a of the polishing pad 102 changes depending on the frictional heat. Accordingly, the temperature of the polishing surface 102a of the polishing pad 102 changes with the progress of polishing of the wafer W.

As shown in FIG. 16, the polishing apparatus is provided with a temperature sensor 107 for measuring the temperature of the polishing surface 102a of the polishing
10 pad 102 (which hereinafter may be referred to simply as the surface temperature). The temperature sensor 107 is a non-contact temperature sensor disposed above the polishing pad 102. A radiation thermometer, for example, may be used as the temperature sensor 107. During polishing of the wafer W, the surface temperature of the polishing pad 102 is measured by the temperature sensor 107, and a measured value of the surface
15 temperature is sent to a polishing operation controller 109. Based on the measured value of the surface temperature of the polishing pad 102, the polishing operation controller 109 monitors the polishing process and determines a polishing end point.

However, since the temperature sensor 107 measures the surface temperature of a portion, lying at a distance from the wafer W, of the polishing pad 102, the measured
20 value of the surface temperature may not reflect a change in a temperature of the wafer W which is a heat source. Furthermore, since the position of the temperature sensor 107 with respect to the wafer W is fixed, the temperature sensor 107 cannot measure the temperature at a desired measuring point near the surface of the wafer W.

25 SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a polishing apparatus and a polishing method capable of polishing a substrate (e.g., wafer) while accurately measuring a temperature at a desired measuring point near a surface of the substrate.

According to one aspect of the present invention, there is provided a polishing apparatus comprising: a polishing pad having a polishing surface for polishing a substrate; a polishing table supporting the polishing pad; a table motor configured to rotate the polishing table; a polishing head configured to press a surface of the substrate against the polishing surface of the polishing pad; a polishing liquid supply nozzle configured to supply a polishing liquid onto the polishing surface of the polishing pad; and a temperature sensor mounted to the polishing table, the temperature sensor being located so as to move across the surface of the substrate each time the polishing table makes one revolution.

10 In a preferred aspect, the temperature sensor is disposed under the polishing pad and can measure a temperature of a lower surface of the polishing pad.

In a preferred aspect, the polishing pad has a recess in the lower surface, and a distal end of the temperature sensor lies in the recess.

15 In a preferred aspect, the polishing pad has a through-hole, a distal end of the temperature sensor lies in the through-hole, and the temperature sensor can measure a temperature of the polishing liquid present in the through-hole.

In a preferred aspect, the polishing apparatus further comprises a polishing operation controller configured to determine a polishing end point of the substrate based on an output value of the temperature sensor.

20 In a preferred aspect, the temperature sensor comprises a thermocouple.

In a preferred aspect, the temperature sensor comprises a combination of an eddy-current sensor and a sensor target made of a conductive material.

25 According to one aspect of the present invention, there is provided a polishing apparatus comprising: a polishing pad having a polishing surface, a bottom surface, and a through-hole extending from the polishing surface to the bottom surface; a polishing table supporting the polishing pad; a polishing head configured to press a surface of a substrate against the polishing surface of the polishing pad; an eddy-current sensor mounted to the polishing table, a distal end of the eddy-current sensor lying in the through-hole of the

polishing pad; and a sensor target disposed in the through-hole of the polishing pad.

In a preferred aspect, a relative position between the sensor target and the eddy-current sensor is fixed.

In a preferred aspect, the polishing apparatus further comprises a ferrite disposed
5 in the through-hole of the polishing pad.

In a preferred aspect, the ferrite is aligned with the eddy-current sensor.

In a preferred aspect, the ferrite is not in contact with the eddy-current sensor and the sensor target.

According to one aspect of the present invention, there is provided a polishing
10 method comprising: rotating a polishing table supporting a polishing pad having a polishing surface; pressing a surface of a substrate against the polishing surface of the polishing pad while supplying a polishing liquid onto the polishing surface constituted by an upper surface of the polishing pad; and obtaining an output value of a temperature sensor which is mounted to the polishing table, while moving the temperature sensor
15 across the surface of the substrate with a rotation of the polishing table.

In a preferred aspect, obtaining the output value of the temperature sensor comprising measuring a temperature of a lower surface of the polishing pad by the temperature sensor while moving the temperature sensor across the surface of the substrate with the rotation of the polishing table.

20 In a preferred aspect, obtaining the output value of the temperature sensor comprising measuring a temperature of the polishing liquid, which is present between the substrate and the temperature sensor, by the temperature sensor while moving the temperature sensor across the surface of the substrate with the rotation of the polishing table.

25 In a preferred aspect, the polishing apparatus further comprises determining a polishing end point of the substrate based on the output value of the temperature sensor.

According to the present invention, a temperature at a desired measuring point near a surface of a substrate (e.g., wafer) can be accurately measured through the

polishing pad or the polishing liquid. Therefore, the progress of the polishing process can be accurately monitored based on a measured value of the temperature. Furthermore, a polishing end point of the substrate can be accurately determined based on a measured value of the temperature.

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BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view showing a polishing apparatus according to an embodiment of the present invention;

FIG. 2 is a diagram showing an arrangement of the temperature sensor shown in
10 FIG. 1;

FIG. 3 is a cross-sectional view of a wafer surface to be polished;

FIG. 4 is a graph showing temperature of a lower surface of a polishing pad which changes with progress of polishing of a wafer;

FIG. 5 is a cross-sectional view showing another example of the arrangement of
15 the temperature sensor;

FIG. 6 is a cross-sectional view showing yet another example of the arrangement of the temperature sensor;

FIG. 7 is a schematic view showing a combination of an eddy-current sensor and a sensor target which are used as a temperature sensor;

FIG. 8 is a graph showing a relationship between temperature of the sensor target and output value of the eddy-current sensor;
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FIG. 9 is a diagram illustrating an embodiment in which the combination of the eddy-current sensor and the sensor target, shown in FIG. 7, is used as the temperature sensor shown in FIG. 5;

FIG. 10 is a diagram illustrating an embodiment in which the combination of the eddy-current sensor and the sensor target, shown in FIG. 7, is used as the temperature sensor shown in FIG. 6;
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FIG. 11 is a diagram illustrating yet another embodiment in which a combination

of an eddy-current sensor and a sensor target is used as a temperature sensor;

FIG. 12 is a diagram illustrating yet another embodiment in which a combination of an eddy-current sensor and a sensor target is used as a temperature sensor;

FIG. 13 is a top view of a ferrite shown in FIG. 12;

5 FIG. 14 is a diagram illustrating yet another embodiment in which a combination of an eddy-current sensor and a sensor target is used as a temperature sensor;

FIG. 15 is a cross-sectional view showing a polishing head which is configured to be able to apply different pressing forces to different zones of a wafer; and

10 FIG. 16 is a perspective view showing a conventional polishing apparatus for polishing a wafer chemically and mechanically.

DESCRIPTION OF EMBODIMENTS

Embodiments of the present invention will now be described with reference to the drawings.

15 FIG. 1 is a schematic view showing a polishing apparatus according to an embodiment of the present invention. As shown in FIG. 1, the polishing apparatus includes a polishing table 3 supporting a polishing pad 2, a polishing head 1 for pressing a wafer W against the polishing pad 2, a table motor 6 for rotating the polishing table 3, and a polishing liquid supply nozzle 5 for supplying a polishing liquid (e.g., slurry or pure
20 water) onto the polishing pad 2. The polishing pad 2 has a surface that constitutes a polishing surface 2a for polishing the wafer W. The polishing table 3 is coupled to the table motor 6 which is configured to rotate the polishing table 3 and the polishing pad 2.

The wafer W is polished in the following manner. While the polishing table 3 and the polishing head 1 are rotated in directions indicated by arrows shown in FIG. 1, the
25 polishing liquid is supplied from the polishing liquid supply nozzle 5 to the polishing surface 2a of the polishing pad 2 on the polishing table 3. The wafer W is rotated by the polishing head 1, while the wafer W is pressed against the polishing surface 2a of the polishing pad 2 in the presence of the polishing liquid between the polishing pad 2 and

the wafer W. The surface of the wafer W is polished by a mechanical action of abrasive particles contained in the polishing liquid and by a chemical action of the polishing liquid.

A temperature sensor 7 is disposed in the polishing table 3. The temperature sensor 7 rotates together with the polishing table 3 and the polishing pad 2. A position of the temperature sensor 7 is such that the temperature sensor 7 sweeps across a surface (i.e., a lower surface to be polished) of the wafer W on the polishing pad 2 each time the polishing table 3 and the polishing pad 2 make one revolution. The temperature sensor 7 is coupled to a polishing operation controller 9 so that a temperature measurement value, which is an output value of the temperature sensor 7, is sent to the polishing operation controller 9.

FIG. 2 is a diagram showing an arrangement of the temperature sensor 7 shown in FIG. 1. The temperature sensor 7 is disposed in a hole 3a formed in the polishing table 3, and is located under the polishing pad 2. The hole 3a is open in an upper surface of the polishing table 3. An upper end of the temperature sensor 7 is in contact with a lower surface of the polishing pad 2 so that the temperature sensor 7 measures the temperature of the lower surface of the polishing pad 2. The temperature sensor 7 is configured to send its output value, namely a measured value of the temperature of the lower surface of the polishing pad 2, to the polishing operation controller 9.

The temperature sensor 7 measures the temperature of the surface (i.e., the lower surface to be polished) of the wafer W indirectly through the polishing pad 2. An amount E (w) of heat generated by polishing of the wafer W can be determined as follows:

$$E(w) = A \cdot \lambda_0 \cdot (t_1 - t_0) / Th_0 \quad (1)$$

where A represents a surface area [m²] of the wafer W, λ_0 represents a thermal conductivity [w/m·k] of the polishing pad 2, Th₀ represents a thickness [m] of the polishing pad 2, t₀ represents a temperature of the polishing surface (upper surface) 2a of the polishing pad 2, and t₁ represents a temperature of the lower surface of the polishing pad 2.

The values of A , λ_0 and Th_0 in the equation (1) are substantially constant. It will therefore be appreciated from the equation (1) that the amount $E(w)$ of heat is proportional to a difference in temperature " $t_1 - t_0$ " between the polishing surface 2a and the lower surface of the polishing pad 2. The temperature t_0 of the polishing surface 2a of the polishing pad 2 changes with the amount $E(w)$ of heat generated by polishing of the wafer W. Accordingly, the temperature t_1 of the lower surface of the polishing pad 2 changes approximately in response to a change in the temperature of the polishing surface 2a of the polishing pad 2.

During polishing of the wafer W, the temperature of the lower surface (and the temperature of the polishing surface 2a) of the polishing pad 2 changes depending on a shape and a material of the surface, to be polished, of the wafer W. FIG. 3 is a cross-sectional view of the surface, to be polished, of the wafer W. As shown in FIG. 3, the surface of the wafer W is composed of a first film 11 and has recesses 12 that reflect configurations of interconnect trenches. The first film 11 is formed on a second film 13. The first film 11 and the second film 13 are made of different materials. In an initial polishing stage, the first film 11 is polished until the recesses 12 are removed. After the recesses 12 are removed, the first film 11 is further polished until the second film 13 is exposed (a second polishing stage).

FIG. 4 is a graph showing the temperature of the lower surface of the polishing pad 2 which changes with the progress of polishing of the wafer W. In the initial polishing stage, the temperature of the lower surface of the polishing pad 2 gradually increases. This is because, as the recesses 12 of the wafer W are removed, an area of the surface of the wafer W increases, i.e., the frictional resistance increases. In the second polishing stage, the area of the surface of the wafer W is constant, and therefore the temperature of the lower surface of the polishing pad 2 is also constant.

The second film 13, underlying the first film 11, becomes exposed upon the removal of the first film 11. The second film 13 has a friction coefficient which is different from that of the first film 11. Therefore, the amount $E(w)$ of heat changes

when the second film 13 is exposed. The change in the amount $E(w)$ of heat appears as a change in the temperature of the lower surface of the polishing pad 2. Thus, the output value of the temperature sensor 7 (i.e., the measured value of the temperature of the lower surface of the polishing pad 2) changes in response to the progress of polishing of the wafer W.

The polishing operation controller 9 determines a polishing end point of the wafer W based on the acquired output value of the temperature sensor 7. More specifically, the polishing operation controller 9 determines a polishing end point at which the output value of the temperature sensor 7 changes after the output value has been kept constant for a predetermined period of time.

Each time the polishing table 3 makes one revolution, the temperature sensor 7 moves across the surface of the wafer W on the polishing pad 2 while measuring the temperature of the lower surface of the polishing pad 2 from below a plurality of points on the wafer W. Preferably, the temperature sensor 7 measures the temperature of the lower surface of the polishing pad 2 from below a plurality of points, including the center of the wafer W, on the wafer W. Since the lower surface of the polishing pad 2 lies in close proximity to the surface, to be polished, of the wafer W, the temperature sensor 7 can obtain a temperature near the temperature of the surface of the wafer W. Moreover, since the output value of the temperature sensor 7 changes in response to a change in the temperature of the surface of the wafer W, the polishing operation controller 9 can monitor the progress of polishing of the wafer W and accurately detect the polishing end point of the wafer W based on the output value of the temperature sensor 7.

The temperature sensor 7 may measure the temperature of the lower surface of the polishing pad 2 when the temperature sensor 7 comes to a position under a predetermined point on the wafer W with the rotation of the polishing table 3. For example, the temperature sensor 7 may measure the temperature of the lower surface of the polishing pad 2 from below the center of the wafer W each time the polishing table 3 makes one revolution. The temperature sensor 7, while sweeping across the surface of

the wafer W, may measure the temperature of the lower surface of the polishing pad 2 at a plurality of measuring points, and the polishing operation controller 9 may calculate an average of temperature measurement values obtained at the plurality of measuring points. The temperature measurement values may be processed by the polishing operation
5 controller 9 of the polishing apparatus. As an alternative, part of processing of the temperature measurement values may be performed by a host computer, and the polishing apparatus may use the processing result.

FIG. 5 is a cross-sectional view showing another example of the arrangement of the temperature sensor 7. In the example shown in FIG. 5, the polishing pad 2 has a
10 recess 2b in the lower surface. A distal end of the temperature sensor 7 lies in the recess 2b. The temperature sensor 7 measures the temperature of the recess 2b constituting a part of the lower surface of the polishing pad 2. Since the lower surface of the polishing pad 2 has the recess 2b, the temperature sensor 7 can be located nearer to the surface, to be polished, of the wafer W as compared to the arrangement shown in FIG. 2. The
15 temperature sensor 7 can therefore obtain a temperature nearer to the temperature of the surface of the wafer W.

FIG. 6 is a cross-sectional view showing yet another example of the arrangement of the temperature sensor 7. In the example shown in FIG. 6, the polishing pad 2 has a
through-hole 2c. A distal end of the temperature sensor 7 lies in the through-hole 2c.
20 During polishing of the wafer W, the polishing liquid is supplied onto the polishing pad 2, and the polishing liquid flows into the through-hole 2c of the polishing pad 2. The polishing liquid existing in the through-hole 2c is in contact with the distal end of the temperature sensor 7 and the surface of the wafer W. The temperature sensor 7 measures the temperature of the polishing liquid present in the through-hole 2c.

25 The temperature sensor 7 measures the temperature of the surface (i.e., the lower surface to be polished) of the wafer W indirectly through a layer of the polishing liquid present in the through-hole 2c. The amount $E(w)$ of heat generated by polishing of the wafer W can be determined as follows:

$$E(w) = A \cdot \lambda_1 \cdot (t_1 - t_0) / Th_1 \quad (2)$$

where A represents a surface area [m²] of the wafer W, λ_1 represents a thermal conductivity [w/m·k] of the polishing liquid, Th₁ represents a thickness [m] of the layer of the polishing liquid, t₀ represents a temperature of an upper surface of the layer of the polishing liquid, and t₁ represents a temperature of a lower surface of the layer of the polishing liquid.

The values of A, λ_1 and Th₁ in the equation (2) are substantially constant. It will therefore be appreciated from the equation (2) that the amount E (w) of heat is proportional to a difference in temperature “t₁ – t₀” between the upper surface and the lower surface of the layer of the polishing liquid. The temperature t₀ of the upper surface of the layer of the polishing liquid changes with the amount E (w) of heat generated by polishing of the wafer W. Accordingly, the temperature t₁ of the lower surface of the layer of the polishing liquid in the through-hole 2c changes approximately in response to a change in the temperature of the to-be-polished surface of the wafer W.

The temperature sensor 7 shown in FIGS. 2, 5 and 6 measures the temperature of a measurement object when the temperature sensor 7 is in contact with the measurement object. The temperature sensor 7 may be a thermocouple or a combination of an eddy-current sensor and a sensor target.

FIG. 7 is a schematic view showing a combination of an eddy-current sensor 7A and a sensor target 7B which are used as the temperature sensor 7. As shown in FIG. 7, the eddy-current sensor 7A is disposed in the polishing table 3. The eddy-current sensor 7A and the sensor target 7B are disposed in a hole 3a formed in the polishing table 3. The sensor target 7B is attached to the lower surface of the polishing pad 2. The eddy-current sensor 7A is disposed just below the sensor target 7B and faces the sensor target 7B. A relative position between the eddy-current sensor 7A and the sensor target 7B is fixed, and thus a distance between the eddy-current sensor 7A and the sensor target 7B is constant at all times. The eddy-current sensor 7A is coupled to the polishing operation controller 9 so that an output value of the eddy-current sensor 7A is sent to the polishing

operation controller 9.

The sensor target 7B is made of a conductive material, such as a metal (e.g., Pt (platinum)). The eddy-current sensor 7A induces an eddy current in the sensor target 7B, and measures a distance from the sensor target 7B based on a change in an impedance of
5 an electrical circuit including the sensor target 7B and the eddy-current sensor 7A. In other words, the output value of the eddy-current sensor 7A is constant if the distance between the eddy-current sensor 7A and the sensor target 7B is constant.

A resistance of the sensor target 7B changes in accordance with the temperature of the sensor target 7B, and a change in the resistance of the sensor target 7B causes a
10 change in the impedance. Therefore, so long as the distance between the eddy-current sensor 7A and the sensor target 7B is constant, the output value of the eddy-current sensor 7A changes in response to a change in the temperature of the sensor target 7B.

A resistance R of the sensor target 7B can be expressed by the following equation (3):

$$15 \quad R = \rho \cdot (L/S) \quad (3)$$

where L is a length (or thickness) of the sensor target 7B, S is a cross-sectional area of the sensor target 7B, and ρ is a resistivity of the sensor target 7B.

As can be seen from the equation (3), under the condition of no change in L and S , the resistance R of the sensor target 7B does not change unless the resistivity ρ changes.

20 The resistivity ρ of the sensor target 7B changes under the influence of the temperature. Specifically, the resistivity ρ can be expressed by the following equation (4):

$$\rho = \rho_0 \cdot [1 + \alpha(T - T_0)] \quad (4)$$

where α is a temperature coefficient of resistance, T_0 is an arbitrary reference
25 temperature near room temperature, ρ_0 is the resistivity at the reference temperature T_0 , and T is a temperature of the sensor target 7B.

As can be seen from the equation (4), the resistivity ρ of the sensor target 7B changes depending on the temperature T of the sensor target 7B. Therefore, under the

condition that the distance between the eddy-current sensor 7A and the sensor target 7B is constant, the output value of the eddy-current sensor 7A changes in response to a change in the temperature of the sensor target 7B.

FIG. 8 is a graph showing a relationship between the temperature of the sensor target 7B and the output value of the eddy-current sensor 7A. In FIG. 8, vertical axis represents the output value [V] of the eddy-current sensor 7A, and horizontal axis represents the temperature [°C] of the sensor target 7B. As shown in FIG. 8, the output value of the eddy-current sensor 7A changes approximately linearly in accordance with the temperature of the sensor target 7B. Therefore, the temperature of the sensor target 7B can be determined uniquely from the output value of the eddy-current sensor 7A.

The polishing operation controller 9 has correlation data, stored therein, showing a relationship between the temperature of the sensor target 7B and the output value of the eddy-current sensor 7A as shown in FIG. 8. The correlation data shown in FIG. 8 can be created by obtaining output values of the eddy-current sensor 7A while changing the temperature of the sensor target 7B, and establishing a relationship between temperatures of the sensor target 7B and the corresponding output values of the eddy-current sensor 7A. The correlation data can be expressed in the form of a linear function, a data table, etc. The polishing operation controller 9 obtains an output value of the eddy-current sensor 7A during polishing of the wafer W, and determines the temperature of the sensor target 7B from the output value of the eddy-current sensor 7A and the correlation data.

Since the sensor target 7B is in contact with the lower surface of the polishing pad 2, the temperature of the sensor target 7B changes in accordance with a change in the temperature of the polishing surface 2a of the polishing pad 2. The polishing operation controller 9 can therefore determine the polishing end point based on the temperature of the sensor target 7B obtained from the output value of the eddy-current sensor 7A.

As shown in FIG. 9, the combination of the eddy-current sensor 7A and the sensor target 7B, shown in FIG. 7, may be used as the temperature sensor 7 shown in FIG. 5. In the embodiment illustrated in FIG. 9, the sensor target 7B is disposed in the recess

2b constituting a part of the lower surface of the polishing pad 2 and is in contact with the lower surface of the polishing pad 2 (i.e., an upper surface of the recess 2b).

As shown in FIG. 10, the combination of the eddy-current sensor 7A and the sensor target 7B, shown in FIG. 7, may be used as the temperature sensor 7 shown in FIG.

5 6. In the embodiment illustrated in FIG. 10, the sensor target 7B is disposed in the through-hole 2c formed in the polishing pad 2, with the upper surface of the sensor target 7B lying lower than the polishing surface 2a of the polishing pad 2. The polishing liquid (e.g., slurry or pure water) that has been supplied to the polishing pad 2 flows into the through-hole 2c and comes into contact with the sensor target 7B.

10 FIG. 11 is a diagram illustrating yet another embodiment in which a combination of an eddy-current sensor 7A and a sensor target 7B is used as a temperature sensor 7. Structures of this embodiment, which are the same as those of the above-described embodiments, are not described particularly, and duplicate descriptions thereof are omitted. The polishing pad 2 has a through-hole 2c extending from the polishing surface
15 2a to a bottom surface 2d of the polishing pad 2. The sensor target 7B is disposed in the through-hole 2c. The eddy-current sensor 7A is mounted to the polishing table 3. The eddy-current sensor 7A is disposed under the sensor target 7B, with the distal end (upper end) of the eddy-current sensor 7A lying in the through-hole 2c. The relative position between the sensor target 7B and the eddy-current sensor 7A is fixed, and thus the
20 distance between the sensor target 7B and the eddy-current sensor 7A is constant at all times.

The sensor target 7B is made of a conductive material, such as a metal. The sensor target 7B is disposed in the through-hole 2c of the polishing pad 2 so as to close the through-hole 2c, so that the sensor target 7B can prevent the polishing liquid (e.g.,
25 slurry) from passing through the through-hole 2c. The sensor target 7B is located lower than the polishing surface 2a of the polishing pad 2 and higher than the bottom surface 2d of the polishing pad 2. The polishing liquid on the polishing surface 2a flows into the through-hole 2c and comes into contact with the sensor target 7B. In order to prevent

corrosion of the sensor target 7B by the polishing liquid, the sensor target 7B may be covered with a protective film.

The eddy-current sensor 7A is housed in a sensor housing 16 and is secured to the polishing table 3. The eddy-current sensor 7A includes a ferrite core 14, and a
5 plurality of coils 15 attached to the ferrite core 14. The coils 15 comprise a detection coil, an exciting coil, and a dummy coil. The coils 15 may be of a solenoid type or of a spiral type.

The sensor housing 16 is secured to a hole 3a formed in the polishing table 3. A distal end (or an upper end) of the sensor housing 16 and the distal end (upper end) of
10 the ferrite core 14 of the eddy-current sensor 7A lie in the through-hole 2c of the polishing pad 2. A gap is formed between the eddy-current sensor 7A and the sensor target 7B, i.e., the eddy-current sensor 7A is not in contact with the sensor target 7B, in order to prevent heat transfer from the sensor target 7B to the eddy-current sensor 7A and to thereby maintain the sensing accuracy of the eddy-current sensor 7A.

15 Since the through-hole 2c is formed in the polishing pad 2 in this embodiment, the temperature of the surface of the wafer W is well transmitted through the polishing liquid to the sensor target 7B. Therefore, the output value of the eddy-current sensor 7A changes in accordance with a change in the temperature of the surface of the wafer W. Further, since the distal end of the eddy-current sensor 7A is located in the polishing pad
20 2, the distance between the eddy-current sensor 7A and the sensor target 7B is small. Therefore, the magnetic flux of the eddy-current sensor 7A does not reach the polishing pad 2 around the sensor target 7B, and an effective measurement range of the eddy-current sensor 7A can fall within the sensor target 7B. As a result, the output value of the eddy-current sensor 7A can change quickly in response to the temperature of the
25 sensor target 7B which is in contact with the polishing liquid. The polishing operation controller 9 can monitor the progress of polishing of the wafer W and can accurately detect the polishing end point of the wafer W based on the output value of the eddy-current sensor 7A.

FIG. 12 is a diagram illustrating yet another embodiment in which a combination of an eddy-current sensor 7A and a sensor target 7B is used as a temperature sensor 7. Structures of this embodiment, which are the same as those of the above-described embodiment shown in FIG. 11, are not described particularly, and duplicate descriptions thereof are omitted.

In this embodiment, a ferrite 17 is disposed in the through-hole 2c of the polishing pad 2. FIG. 13 is a top view of the ferrite 17. The ferrite 17 has a shape corresponding to the shape of the ferrite core 14 of the eddy-current sensor 7A. Specifically, the ferrite 17 includes a circular central ferrite 17a, and an annular outer ferrite 17b disposed around the central ferrite 17a. It is noted that the shape of the ferrite 17, shown in FIG. 13, is merely an example and can vary depending on the shape of the ferrite core 14 of the eddy-current sensor 7A.

As shown in FIG. 12, the distal end (upper end) of the sensor housing 16 and the distal end (upper end) of the ferrite core 14 of the eddy-current sensor 7A lie in the through-hole 2c of the polishing pad 2. The ferrite 17 is disposed above the eddy-current sensor 7A and aligned with the eddy-current sensor 7A. The ferrite 17 is held by a ferrite holder 18 formed of a synthetic resin, such as polypropylene. More specifically, the ferrite 17 is embedded in the ferrite holder 18. This ferrite holder 18 is secured to the sensor housing 16. Thus, a relative position between the ferrite 17 and the eddy-current sensor 7A in the sensor housing 16 is fixed. A lower end of the ferrite holder 18 closes an opening of the sensor housing 16 so that the polishing liquid does not come into contact with the eddy-current sensor 7A.

The ferrite 17 can focus the magnetic flux of the eddy-current sensor 7A on the sensor target 7B, so that the effective measurement range of the eddy-current sensor 7A can fall within the sensor target 7B. Therefore, the output value of the eddy-current sensor 7A can change quickly in response to the temperature of the sensor target 7B which is in contact with the polishing liquid.

The ferrite 17 and the ferrite holder 18 may preferably be not in contact with the

eddy-current sensor 7A and the sensor target 7B in order to prevent the heat transfer from the sensor target 7B to the eddy-current sensor 7A and to thereby maintain the sensing accuracy of the eddy-current sensor 7A.

FIG. 14 is a diagram illustrating yet another embodiment in which a combination
5 of an eddy-current sensor 7A and a sensor target 7B is used as a temperature sensor 7. Structures of this embodiment, which are the same as those of the above-described embodiment shown in FIG. 12, are not described particularly, and duplicate descriptions thereof are omitted.

This embodiment is the same as the above-described embodiment in that the
10 sensor target 7B is disposed in the through-hole 2c of the polishing pad 2, but differs in that the sensor target 7B does not close the through-hole 2c and has a shape that covers the ferrite 17. In particular, the sensor target 7B has a shape of a container which is open downwardly and covers the ferrite holder 18 and the ferrite 17. The lower end of the sensor target 7B and/or the lower end of the ferrite holder 18 closes the opening of the
15 sensor housing 16 so that the polishing liquid does not come into contact with the eddy-current sensor 7A.

The temperature sensor 7 according to each of the above-described embodiments moves across the surface of the wafer W each time the polishing table 3 makes one revolution. Therefore, the polishing operation controller 9 can obtain data of a
20 temperature distribution along the radial direction of the wafer W. Further, based on the temperature distribution, the polishing operation controller 9 can operate the polishing head 1 to apply different pressing forces to multiple zones of the wafer W.

FIG. 15 is a cross-sectional view showing the polishing head 1 capable of applying different pressing forces to different zones of the wafer W. The polishing head
25 1 has a polishing head body 21 coupled to a head shaft 10, and a retaining ring 22 provided below the polishing head body 21.

A flexible membrane 24 to be brought into contact with an upper surface (a surface at an opposite side of the surface to be polished) of wafer W and a membrane

holder 25 that holds the membrane 24 are disposed below the polishing head body 21. Four pressure chambers C1, C2, C3, and C4 are provided between the membrane 24 and the membrane holder 25. The pressure chambers C1, C2, C3, and C4 are formed by the membrane 24 and the membrane holder 25. The central pressure chamber C1 has a circular shape, and the other pressure chambers C2, C3, and C4 have an annular shape. These pressure chambers C1, C2, C3, and C4 are in a concentric arrangement.

Pressurized gas, such as pressurized air, is supplied from a gas supply source 30 through gas delivery lines F1, F2, F3, and F4 into the pressure chambers C1, C2, C3, and C4, respectively. Vacuum lines V1, V2, V3, and V4 are coupled to the gas delivery lines F1, F2, F3, and F4, respectively, so that negative pressure can also be produced in the pressure chambers C1, C2, C3, and C4 by the vacuum lines V1, V2, V3, and V4. The pressures in the pressure chambers C1, C2, C3, and C4 can be changed independently to thereby independently adjust polishing pressures on four zones of the wafer W: a central portion; an inner intermediate portion; an outer intermediate portion; and a peripheral portion.

A pressure chamber C5 is formed between the membrane holder 25 and the polishing head body 21. The pressurized gas is supplied from the gas supply source 30 through a gas delivery line F5 into the pressure chamber C5. Further, a vacuum line V5 is coupled to the gas delivery line F5, so that negative pressure can also be produced in the pressure chamber C5 by the vacuum line V5. With these operations, the membrane holder 25 and the entirety of the membrane 24 can move up and down.

The retaining ring 22 is arranged around the peripheral portion of the wafer W so as to prevent the wafer W from coming off the polishing head 1 during polishing. The membrane 24 has an opening in a portion that forms the pressure chamber C3, so that the wafer W can be held on the polishing head 1 by vacuum suction when a vacuum is produced in the pressure chamber C3. Further, the wafer W can be released from the polishing head 1 by supplying nitrogen gas or clean air into the pressure chamber C3.

An annular rolling diaphragm 26 is provided between the polishing head body 21

and the retaining ring 22. A pressure chamber C6 is formed in this rolling diaphragm 26, and is in communication with the gas supply source 30 through a gas delivery line F6. The gas supply source 30 supplies the pressurized gas into the pressure chamber C6, so that the rolling diaphragm 26 presses the retaining ring 22 against the polishing pad 2.
5 Further, a vacuum line V6 is coupled to the gas delivery line F6 so that negative pressure can also be produced in the pressure chamber C6 by the vacuum line V6. When a vacuum is produced in the pressure chamber C6, the entirety of the retaining ring 22 is elevated.

The gas delivery lines F1, F2, F3, F4, F5, and F6, communicating with the
10 pressure chambers C1, C2, C3, C4, C5, and C6, respectively, are provided with electropneumatic regulators (or pressure regulators) R1, R2, R3, R4, R5, and R6, respectively. The pressurized gas from the gas supply source 30 is supplied through the electropneumatic regulators R1 to R6 into the pressure chambers C1 to C6. These electropneumatic regulators R1 to R6 are coupled to the pressure chambers C1 to C6 via
15 the gas delivery lines F1 to F6, which extend from the pressure chambers C1 to C6 through a rotary joint 28 to the gas supply source 30.

The electropneumatic regulators R1 to R6 are configured to regulate the pressure in the pressure chambers C1 to C6 by regulating the pressure of the pressurized gas supplied from the gas supply source 30. The electropneumatic regulators R1 to R6 are
20 coupled to the polishing operation controller 9. The pressure chambers C1 to C6 are further coupled to vent valves (not shown), respectively, so that the pressure chambers C1 to C6 can be ventilated to the atmosphere.

The polishing operation controller 9 is configured to establish target pressure values for the pressure chambers C1 to C6 and manipulate the electropneumatic
25 regulators (pressure regulators) R1 to R6 such that the pressures in the pressure chambers C1 to C6 are maintained at the corresponding target pressure values. In particular, the polishing operation controller 9 creates a temperature distribution along the radial direction of the wafer W using the output values of the temperature sensor 7, determines

the target pressure values for the pressure chambers C1 to C4 based on the temperature distribution, and manipulates the electropneumatic regulators (pressure regulators) R1 to R4 such that the pressures in the pressure chambers C1 to C4 are maintained at the corresponding target pressure values. For example, the polishing operation controller 9
5 decreases the pressure in the pressure chamber corresponding to a wafer zone having a higher temperature, and increases the pressure in the pressure chamber corresponding to a wafer zone having a lower temperature.

The output value of the temperature sensor 7 may be transmitted to a host computer (e.g., a computer connected to various semiconductor manufacturing devices in
10 a facility and managing these devices), which may accumulate the output value of the temperature sensor 7. Furthermore, the host computer may determine the polishing end point based on a distribution of the output values of the temperature sensor 7 sent from the polishing apparatus, or may determine a polishing condition in a processing module for a wafer W based on an amount of polishing with respect to a polishing condition that
15 is stored in a data base of the host computer, and may transmit the determined polishing condition to the polishing operation controller 9 of the polishing apparatus.

While the four pressing chamber C1 to C4 are provided for pressing the wafer W in the embodiment shown in FIG. 15, less than four pressure chambers or more than four pressure chambers may be provided.

20 The previous description of embodiments is provided to enable a person skilled in the art to make and use the present invention. Moreover, various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles and specific examples defined herein may be applied to other embodiments. Therefore, the present invention is not intended to be limited to the embodiments
25 described herein but is to be accorded the widest scope as defined by limitation of the claims and equivalents.

What is claimed is:

1. A polishing apparatus comprising:
 - a polishing pad having a polishing surface for polishing a substrate;
 - 5 a polishing table supporting the polishing pad;
 - a table motor configured to rotate the polishing table;
 - a polishing head configured to press a surface of the substrate against the polishing surface of the polishing pad;
 - a polishing liquid supply nozzle configured to supply a polishing liquid onto the
 - 10 polishing surface of the polishing pad; and
 - a temperature sensor mounted to the polishing table, the temperature sensor being located so as to move across the surface of the substrate each time the polishing table makes one revolution.
- 15 2. The polishing apparatus according to claim 1, wherein the temperature sensor is disposed under the polishing pad and can measure a temperature of a lower surface of the polishing pad.
3. The polishing apparatus according to claim 2, wherein the polishing pad has
- 20 a recess in the lower surface, and a distal end of the temperature sensor lies in the recess.
4. The polishing apparatus according to claim 1, wherein the polishing pad has a through-hole, a distal end of the temperature sensor lies in the through-hole, and the temperature sensor can measure a temperature of the polishing liquid present in the
- 25 through-hole.
5. The polishing apparatus according to claim 1, further comprising a polishing operation controller configured to determine a polishing end point of the substrate based

on an output value of the temperature sensor.

6. The polishing apparatus according to claim 1, wherein the temperature sensor comprises a thermocouple.

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7. The polishing apparatus according to claim 1, wherein the temperature sensor comprises a combination of an eddy-current sensor and a sensor target made of a conductive material.

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8. A polishing apparatus comprising:

a polishing pad having a polishing surface, a bottom surface, and a through-hole extending from the polishing surface to the bottom surface;

a polishing table supporting the polishing pad;

15 a polishing head configured to press a surface of a substrate against the polishing surface of the polishing pad;

an eddy-current sensor mounted to the polishing table, a distal end of the eddy-current sensor lying in the through-hole of the polishing pad; and

a sensor target disposed in the through-hole of the polishing pad.

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9. The polishing apparatus according to claim 8, wherein a relative position between the sensor target and the eddy-current sensor is fixed.

10. The polishing apparatus according to claim 8, further comprising a ferrite disposed in the through-hole of the polishing pad.

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11. The polishing apparatus according to claim 10, wherein the ferrite is aligned with the eddy-current sensor.

12. The polishing apparatus according to claim 10, wherein the ferrite is not in contact with the eddy-current sensor and the sensor target.

13. A polishing method comprising:
5 rotating a polishing table supporting a polishing pad having a polishing surface;
pressing a surface of a substrate against the polishing surface of the polishing pad while supplying a polishing liquid onto the polishing surface constituted by an upper surface of the polishing pad; and
10 obtaining an output value of a temperature sensor which is mounted to the polishing table, while moving the temperature sensor across the surface of the substrate with a rotation of the polishing table.

14. The polishing method according to claim 13, wherein obtaining the output value of the temperature sensor comprising measuring a temperature of a lower surface of the polishing pad by the temperature sensor while moving the temperature sensor across
15 the surface of the substrate with the rotation of the polishing table.

15. The polishing method according to claim 13, wherein obtaining the output value of the temperature sensor comprising measuring a temperature of the polishing liquid, which is present between the substrate and the temperature sensor, by the
20 temperature sensor while moving the temperature sensor across the surface of the substrate with the rotation of the polishing table.

16. The polishing method according to claim 13, further comprising
25 determining a polishing end point of the substrate based on the output value of the temperature sensor.