

POLISHING METHOD AND POLISHING APPARATUS

BACKGROUND OF THE INVENTION

Field of the Invention:

5 [0001] The present invention relates to technology for polishing a workpiece, such as a wafer, a substrate, an interconnect substrate, and a quadrilateral substrate, and particularly relates to technology for detecting a polishing endpoint of the workpiece.

Description of the Related Art:

10 [0002] In manufacturing of a semiconductor device, there is a process of polishing a surface of a wafer with a CMP (Chemical Mechanical Polishing) apparatus. The CMP apparatus performs polishing of the wafer as follows. While a polishing table holding a polishing pad is rotating, a polishing liquid (typically slurry containing abrasive grains) is supplied onto the polishing pad. The wafer is pressed against the polishing pad by a polishing head, and brought into sliding contact with the polishing pad. The surface of the wafer is
15 planarized by a combination of chemical action of the polishing liquid and mechanical action of the abrasive grains contained in the polishing liquid and the polishing pad.

[0003] Polishing of the wafer is stopped when an upper layer is polished and a lower layer is exposed. Technologies for detecting such a polishing endpoint of the wafer include a torque monitoring method and a spectrum monitoring method. The torque monitoring
20 method monitors a current (hereinafter referred to as torque current) supplied to an electric motor that rotates the polishing table during polishing of the wafer, and detects the polishing endpoint at which the torque current varies across a threshold value. The spectrum monitoring method irradiates the wafer with light during polishing of the wafer, obtains a cumulative amount of change in spectrum of reflected light from the wafer, and detects the
25 polishing endpoint based on this cumulative amount of change in spectrum.

Citation List

Patent Literature

[0004] [Patent Literature 1] Japanese Patent Laid-Open No. 2013-219248

[Patent Literature 2] Japanese Patent Laid-Open No. 2015-156503

[0005] The polishing endpoint detection of the torque monitoring method described above depends on a change in the torque current, and the polishing endpoint detection of the spectrum monitoring method depends on a change in a polishing rate of the wafer.

5 However, depending on chemical properties of the polishing liquid used for polishing of the wafer, the torque current or the polishing rate of the wafer does not change much when the upper layer is removed and the lower layer is exposed. As a result, the above methods sometimes failed in detection of the polishing endpoint.

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SUMMARY OF THE INVENTION

[0006] Therefore, the present invention provides a polishing method and a polishing apparatus capable of detecting a polishing endpoint at which an upper layer is polished and a lower layer is exposed, without depending on changes in torque current and polishing rate.

[0007] In an embodiment, there is provided a polishing method comprising: supplying a
15 polishing liquid onto a polishing pad on a polishing table while rotating the polishing table; polishing a workpiece in the presence of the polishing liquid by pressing the workpiece against the polishing pad; irradiating the workpiece with light each time the polishing table makes one rotation, and generating a spectrum of reflected light from the workpiece; calculating an index value indicating similarity between the spectrum of the reflected light and an interface spectrum, the interface spectrum being a spectrum of reflected light from a
20 reference workpiece generated when a first film is removed and a second film underlying the first film is exposed during polishing of the reference workpiece; and determining a polishing endpoint at which the index value is maximized or minimized.

[0008] In an embodiment, the index value comprises a plurality of index values calculated
25 according to different calculation algorithms, and the polishing endpoint is a point in time when at least one of the plurality of index values is maximized or minimized.

In an embodiment, the polishing endpoint is a point in time when any one of the plurality of index values is first maximized or minimized.

In an embodiment, the polishing endpoint is a point in time when all of the plurality

of index values are maximized or minimized.

In an embodiment, the reference workpiece has the same surface structure as that of the workpiece.

5 In an embodiment, polishing conditions for the reference workpiece are the same as polishing conditions for the workpiece.

10 In an embodiment, the interface spectrum is obtained in advance by an interface-spectrum acquisition process before polishing of the workpiece, and the interface-spectrum acquisition process includes: generating a theoretical interface spectrum of light reflected from the reference workpiece when the first film is removed and the second film is exposed; generating a plurality of spectra of reflected light from the reference workpiece while polishing the reference workpiece; calculating an index value indicating similarity between each of the plurality of spectra and the theoretical interface spectrum; selecting a spectrum at which the index value is maximized or minimized from among the plurality of spectra; and designating the selected spectrum as the interface spectrum.

15 [0009] In an embodiment, there is provided a polishing apparatus comprising: a polishing table configured to support a polishing pad; a table motor configured to rotate the polishing table; a polishing-liquid supply nozzle configured to supply a polishing liquid onto the polishing pad; a polishing head configured to polish a workpiece in the presence of the polishing liquid by pressing the workpiece against the polishing pad; and an optical system
20 configured to irradiate the workpiece with light each time the polishing table makes one rotation, and generate a spectrum of reflected light from the workpiece, wherein the optical system is configured to: calculate an index value indicating similarity between the spectrum of the reflected light and an interface spectrum, the interface spectrum being a spectrum of reflected light from a reference workpiece generated when a first film is removed and a
25 second film underlying the first film is exposed during polishing of the reference workpiece; and determine a polishing endpoint at which the index value is maximized or minimized.

[0010] In an embodiment, the optical system is configured to: calculate a plurality of index values according to different calculation algorithms; and determine the polishing endpoint at which at least one of the plurality of index values is maximized or minimized.

In an embodiment, the optical system is configured to determine the polishing endpoint at which any one of the plurality of index values is first maximized or minimized.

In an embodiment, the optical system is configured to determine the polishing endpoint at which all of the plurality of index values are maximized or minimized.

5 [0011] When the first film of the workpiece is removed and the second film is exposed by polishing of the workpiece, the spectrum of the reflected light from the workpiece is closest to the interface spectrum. A point in time when the similarity between the spectrum of the reflected light and the interface spectrum is maximized, i.e., a point in time when the index value of the similarity is maximized or minimized indicates the polishing endpoint at which
10 the first film of the workpiece is removed and the second film is exposed. Therefore, the polishing endpoint of the workpiece can be accurately detected based on the index value of the similarity.

BRIEF DESCRIPTION OF THE DRAWINGS

15 [0012] FIG. 1 is a schematic diagram showing an embodiment of a polishing apparatus.

FIG. 2 is a cross-sectional view showing a detailed configuration of an optical system.

FIG. 3 shows an example of a spectrum of reflected light from a workpiece.

20 FIG. 4 is a cross-sectional view showing an example of a surface structure of the workpiece before being polished.

FIGS. 5A to 5C are diagrams showing an example of how the surface structure shown in FIG. 4 changes as the workpiece is polished.

FIG. 6 is a diagram explaining an embodiment in which a plurality of spectra
25 generated during polishing of the workpiece are compared with an interface spectrum one by one, and an index value indicating similarity between these two spectra is calculated.

FIG. 7 is a graph showing an example of a change in the index value indicating similarity between two spectra with polishing time.

FIG. 8 is a flowchart explaining an embodiment of determining the polishing

endpoint of the workpiece described with reference to FIGS. 6 and 7.

FIG. 9 is a flowchart explaining an embodiment of an interface-spectrum determination process.

FIG. 10 is a diagram showing an example of a theoretical interface spectrum.

5 FIG. 11 is a schematic diagram explaining step 203 shown in FIG. 9.

DESCRIPTION OF EMBODIMENTS

[0013] Hereinafter, embodiments of the present invention will be described with reference to the drawings. FIG. 1 is a schematic diagram showing an embodiment of a
10 polishing apparatus. As shown in FIG. 1, the polishing apparatus includes a polishing table 3 configured to support a polishing pad 2, a polishing head 1 configured to press a workpiece W against the polishing pad 2, a table motor 6 configured to rotate the polishing table 3, a polishing-liquid supply nozzle 5 configured to supply a polishing liquid, such as slurry, onto the polishing pad 2, and an operation controller 9 configured to control operations of the
15 polishing apparatus. An upper surface of the polishing pad 2 constitutes a polishing surface 2a for polishing the workpiece W. The workpiece W has a film constituting an interconnect structure on a surface thereof. Examples of the workpiece W include a wafer, a substrate, an interconnect substrate, and a quadrilateral substrate used for manufacturing semiconductor devices. In one example, the workpiece W is a wafer on which multilayered
20 films are formed.

[0014] The polishing head 1 is coupled to a head shaft 10, and the head shaft 10 is coupled to a polishing-head rotating device 15. The polishing-head rotating device 15 is configured to rotate the polishing head 1 together with the head shaft 10 in a direction indicated by an arrow. A configuration of the polishing-head rotating device 15 is not particularly limited,
25 but in one example, the polishing-head rotating device 15 includes an electric motor, a belt, a pulley, and the like. The polishing table 3 is coupled to the table motor 6, and the table motor 6 is configured to rotate the polishing table 3 and the polishing pad 2 in a direction indicated by an arrow. The polishing head 1, the polishing-head rotating device 15, and the table motor 6 are coupled to the operation controller 9.

[0015] The workpiece W is polished as follows. While the table motor 6 and the polishing-head rotating device 15 rotate the polishing table 3 and the polishing head 1 in the directions indicated by the arrows in FIG. 1, the 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.

5 While the workpiece W is rotated by the polishing head 1, the workpiece W is pressed against the polishing surface 2a of the polishing pad 2 by the polishing head 1 in a state where the polishing liquid is present on the polishing pad 2. The surface of the workpiece W is polished by chemical action of the polishing liquid and mechanical action of abrasive grains contained in the polishing liquid and/or the polishing pad 2.

10 [0016] The operation controller 9 includes a memory 9a storing a program, and an arithmetic device 9b configured to execute an arithmetic operation according to instructions included in the program. The operation controller 9 is composed of at least one computer. The memory 9a includes a main memory, such as a random access memory (RAM), and an auxiliary memory, such as a hard disk drive (HDD) and a solid state drive (SSD). Examples
15 of the arithmetic device 9b include a CPU (Central Processing Unit) and a GPU (Graphic Processing Unit). However, a specific configuration of the operation controller 9 is not limited to these examples.

[0017] The polishing apparatus includes an optical system 20 for detecting a polishing endpoint of the workpiece W. The optical system 20 includes a light source 22 configured
20 to emit light, an optical sensor head 25 configured to irradiate the workpiece W with the light of the light source 22 and receive reflected light from the workpiece W, a spectrometer 27 coupled to the optical sensor head 25, and a spectrum processor 30 configured to generate a spectrum of the reflected light from the workpiece W. The optical sensor head 25 is disposed in the polishing table 3 and rotates together with the polishing table 3.

25 [0018] The spectrum processor 30 includes a memory 30a storing a program, and an arithmetic device 30b configured to execute an arithmetic operation according to instructions included in the program. The spectrum processor 30 is composed of at least one computer. The memory 30a includes a main memory, such as a random access memory (RAM), and an auxiliary memory, such as a hard disk drive (HDD) and a solid state drive (SSD). Examples

of the arithmetic device 30b include a CPU (Central Processing Unit) and a GPU (Graphic Processing Unit). However, a specific configuration of the spectrum processor 30 is not limited to these examples.

[0019] Each of the operation controller 9 and the spectrum processor 30 may be composed of a plurality of computers. For example, each of the operation controller 9 and the spectrum processor 30 may be composed of a combination of an edge server and a cloud server. In an embodiment, the operation controller 9 and the spectrum processor 30 may be composed of one computer.

[0020] FIG. 2 is a cross-sectional view showing a detailed configuration of the optical system 20. The optical system 20 includes a light-emitting optical fiber cable 31 coupled to the light source 22, and a light-receiving optical fiber cable 32 coupled to the spectrometer 27. A distal end 31a of the light-emitting optical fiber cable 31 and a distal end 32a of the light-receiving optical fiber cable 32 constitute the optical sensor head 25. Specifically, the light-emitting optical fiber cable 31 directs the light, emitted by the light source 22, onto the workpiece W on the polishing pad 2, and the light-receiving optical fiber cable 32 receives the reflected light from the workpiece W and transmits the reflected light to the spectrometer 27.

[0021] The spectrometer 27 is coupled to the spectrum processor 30. The light-emitting optical fiber cable 31, the light-receiving optical fiber cable 32, the light source 22, and the spectrometer 27 are attached to the polishing table 3, and rotate integrally together with the polishing table 3 and the polishing pad 2. The optical sensor head 25, which is composed of the distal end 31a of the light-emitting optical fiber cable 31 and the distal end 32a of the light-receiving optical fiber cable 32, is disposed so as to face the surface of the workpiece W on the polishing pad 2.

[0022] A position of the optical sensor head 25 is such that the optical sensor head 25 moves across the surface of the workpiece W on the polishing pad 2 each time the polishing table 3 and the polishing pad 2 make one rotation. The polishing pad 2 has a through-hole 2b located above the optical sensor head 25. The optical sensor head 25 irradiates the workpiece W with the light through the through-hole 2b each time the polishing table 3

makes one rotation, and receives the reflected light from the workpiece W through the through-hole 2b.

[0023] In an embodiment, in order to prevent the polishing liquid and polishing debris from coming into contact with the optical sensor head 25, a flow of pure water may be formed in the through-hole 2b of the polishing pad 2. The light is guided from the optical sensor head 25 through the pure water to the workpiece W, and the reflected light from the workpiece W travels through the pure water and is received by the optical sensor head 25. In another embodiment, a transparent window (not shown) may be fitted in the through-hole 2b of the polishing pad 2. The transparent window is made of a material permitting transmission of light (e.g., a transparent resin). In this case, the light is guided from the optical sensor head 25 through the transparent window to the workpiece W, and the reflected light from the workpiece W travels through the transparent window and is received by the optical sensor head 25.

[0024] In an embodiment, the light source 22 is a flash light source configured to repeatedly emit light at short time intervals. An example of the light source 22 is a xenon flash lamp. The light source 22 is electrically coupled to the operation controller 9, and emits the light upon receiving a trigger signal sent from the operation controller 9. More specifically, while the optical sensor head 25 moves across the surface of the workpiece W on the polishing pad 2, the light source 22 receives a plurality of trigger signals and emits the light a plurality of times. Therefore, each time the polishing table 3 makes one rotation, a plurality of measurement points including a center point on the workpiece W are irradiated with the light.

[0025] The light emitted by the light source 22 is transmitted to the optical sensor head 25. Specifically, the light is transmitted through the light-emitting optical fiber cable 31 to the optical sensor head 25, and is emitted from the optical sensor head 25. The light is incident on the workpiece W on the polishing pad 2 through the through-hole 2b of the polishing pad 2. The light reflected from the workpiece W passes through the through-hole 2b of the polishing pad 2 again, and is received by the optical sensor head 25. The reflected light from the workpiece W is transmitted through the light-receiving optical fiber cable 32 to the

spectrometer 27.

[0026] The spectrometer 27 is configured to decompose the reflected light according to wavelength and measure an intensity of the reflected light at each wavelength over a predetermined wavelength range. Specifically, the spectrometer 27 decomposes the reflected light from the workpiece W according to wavelength, measures the intensity of the reflected light at each wavelength over the predetermined wavelength range, and generates light-intensity measurement data. The intensity of the reflected light at each wavelength can be expressed as a relative value, such as reflectance or relative reflectance. The light-intensity measurement data is sent to the spectrum processor 30.

[0027] The spectrum processor 30 generates a spectrum of the reflected light from the light-intensity measurement data. FIG. 3 shows an example of the spectrum of the reflected light from the workpiece W. The spectrum of the reflected light from the workpiece W contains information on film thickness of the workpiece W. In other words, the spectrum of the reflected light changes depending on the film thickness of the workpiece W. The spectrum processor 30 is configured to determine the film thickness and the polishing endpoint of the workpiece W based on the spectrum of the reflected light.

[0028] FIG. 4 is a cross-sectional view showing an example of a surface structure of the workpiece W before being polished. As shown in FIG. 4, the workpiece W before being polished has a surface structure including a first film 101 and a second film 102 formed under the first film 101. Examples of the workpiece W include a wafer, a substrate, an interconnect substrate, and a quadrilateral substrate for use in manufacturing semiconductor devices. A material constituting the first film 101 is different from a material constituting the second film 102. In one example, the first film 101 is an oxide film (for example, a SiO₂ film), and the second film 102 is a polishing stopper film (for example, a SiN film).

[0029] FIGS. 5A to 5C are diagrams showing an example of how the surface structure shown in FIG. 4 changes as the workpiece W is polished. More specifically, FIG. 5A is an initial stage of polishing of the workpiece W, FIG. 5B is an intermediate stage of polishing of the workpiece W, and FIG. 5C is a polishing endpoint of the workpiece W. As shown in FIGS. 5A to 5C, as the workpiece W is polished, the thickness of the first film 101 constituting an

exposed surface of the workpiece W gradually decreases. Polishing of the workpiece W is performed until the first film 101 is removed from the workpiece W and the second film 102 is exposed. Specifically, as shown in FIG. 5C, the polishing endpoint of the workpiece W is a point in time when the first film 101 is removed and the second film 102 is exposed.

5 [0030] The optical system 20 is configured to irradiate the workpiece W with the light and generate the spectrum of the reflected light from the workpiece W each time the polishing table 3 makes one rotation. More specifically, the optical sensor head 25 irradiates the workpiece W with the light and receives the reflected light from the workpiece W each time the polishing table 3 makes one rotation, and the spectrometer 27 measures the intensity of
10 the reflected light from the workpiece W at each of the wavelengths of the reflected light. The spectrum processor 30 generates the spectrum of the reflected light from the light-intensity measurement data, and detects the polishing endpoint of the workpiece W based on the spectrum.

[0031] Hereinafter, an embodiment of detecting the polishing endpoint of the workpiece W
15 will be described. The spectrum processor 30 compares the spectrum of the reflected light with an interface spectrum each time the spectrum of the reflected light from the workpiece W (hereinafter, simply referred to as the spectrum of the reflected light) is generated, and calculates an index value indicating similarity between the spectrum of the reflected light and the interface spectrum. The interface spectrum is a spectrum of reflected light from a
20 reference workpiece generated when the first film is removed and the second film underlying the first film is exposed during polishing of the reference workpiece. The interface spectrum is determined from a result of polishing of the reference workpiece performed before polishing of the workpiece W. A method of determining the interface spectrum using the reference workpiece will be described later.

25 [0032] The spectrum processor 30 is configured to calculate the index value indicating the similarity between the spectrum of the reflected light from the workpiece W and the interface spectrum during polishing of the workpiece W, and determine the polishing endpoint at which the index value is maximized or minimized. The index value is calculated according to a predetermined calculation algorithm.

[0033] The similarity between two spectra indicates how similar shapes of the two spectra are. Each spectrum represents a plurality of intensities of reflected light corresponding to a plurality of wavelengths, respectively, as described with reference to FIG. 3. The plurality of intensities of reflected light corresponding to the plurality of wavelengths, respectively, can be used as a data group representing characteristics of the spectrum. Therefore, the similarity between two spectra can be calculated as similarity between two data groups.

[0034] The index value indicating the similarity between two spectra can be calculated according to a calculation algorithm for calculating similarity between two data groups.

The calculation algorithm differs depending on the type of the index value. Examples of the index value are listed below.

Euclidean distance

Mahalanobis distance

Normalized Cross-Correlation (NCC)

Cosine similarity

However, the index value is not limited to these examples as long as the index value can indicate the similarity between two spectra.

[0035] FIG. 6 is a diagram explaining an embodiment in which a plurality of spectra generated during polishing of the workpiece W are compared with the interface spectrum one by one, and an index value indicating similarity between these two spectra is calculated. As shown in FIG. 6, the spectrum processor 30 generates the spectrum of the reflected light from the workpiece W each time the polishing table 3 makes one rotation. Further, the spectrum processor 30 calculates the index value indicating the similarity between each spectrum of the reflected light and the interface spectrum according to a predetermined calculation algorithm each time the spectrum of the reflected light is generated.

[0036] FIG. 7 is a graph showing an example of a change in the index value indicating the similarity between the two spectra with polishing time. In the example shown in FIG. 7, Euclidean distance, Mahalanobis distance, Normalized Cross-Correlation (NCC), and Cosine similarity are used as index values each indicating the similarity. As shown in FIG.

7, the index value changes with polishing time. The manner of change in the index value depends on the calculation algorithm for calculating the index value. For example, the Euclidean distance and the Mahalanobis distance decrease as the similarity between two spectra increases. On the other hand, the Normalized Cross-Correlation (NCC) and the Cosine similarity increase as the similarity between two spectra increases.

[0037] The spectrum processor 30 may calculate a single index value using one calculation algorithm. For example, the spectrum processor 30 uses the Euclidean distance as the index value, calculates the index value according to the calculation algorithm for calculating the Euclidean distance, and determines the polishing endpoint of the workpiece W which is a point in time when the index value is minimized. In another example, the spectrum processor 30 uses the Cosine similarity as the index value, calculates the index value according to the calculation algorithm for calculating the Cosine similarity, and determines the polishing endpoint of the workpiece W which is a point in time when the index value is maximized.

[0038] In one embodiment, the spectrum processor 30 may calculate a plurality of index values using different calculation algorithms. For example, the spectrum processor 30 uses the Euclidean distance, the Mahalanobis distance, the Normalized Cross-Correlation, and the Cosine similarity as the plurality of index values, calculates the plurality of index values according to different calculation algorithms for calculating these index values, and determines the polishing endpoint of the workpiece W which is a point in time when any one of the plurality of index values first is minimized or maximized. In another example, the spectrum processor 30 determines the polishing endpoint of the workpiece W which is a point in time when all of the plurality of index values are maximized or minimized.

[0039] In an embodiment, the plurality of index values may be two or three index values selected from the Euclidean distance, the Mahalanobis distance, the Normalized Cross-Correlation, and the Cosine similarity. In another embodiment, the index value may be an index value other than the Euclidean distance, the Mahalanobis distance, the Normalized Cross-Correlation, and the Cosine similarity, as long as the index value can indicate the similarity between two spectra.

[0040] When the first film 101 of the workpiece W is removed and the second film 102 is exposed by polishing of the workpiece W, the spectrum of the reflected light from the workpiece W is closest to the interface spectrum. A point in time when the similarity between the spectrum of the reflected light and the interface spectrum is maximized, that is,
5 a point in time when the index value of the similarity is maximized or minimized indicates the polishing endpoint at which the first film 101 of the workpiece W is removed and the second film 102 is exposed. Therefore, the optical system 20 can accurately determine the polishing endpoint of the workpiece W based on the index value of the similarity.

[0041] FIG. 8 is a flowchart explaining an embodiment of determining the polishing
10 endpoint of the workpiece W described with reference to FIGS. 6 and 7.

In step 101, the spectrum processor 30 generates the plurality of spectra of reflected light from the reference workpiece while the reference workpiece is polished by the polishing apparatus shown in FIGS. 1 and 2. The plurality of spectra are generated from the start of polishing to the end of polishing of the reference workpiece.

[0042] In step 102, the spectrum processor 30 determines the interface spectrum from among
15 the plurality of spectra of reflected light from the reference workpiece. This interface spectrum is a spectrum of reflected light from the reference workpiece generated when the first film of the reference workpiece is removed and the second film underlying the first film is exposed during polishing of the reference workpiece. The interface spectrum is stored
20 in the memory 30a of the spectrum processor 30.

[0043] In step 103, the spectrum processor 30 generates a spectrum of reflected light from the workpiece W while the workpiece W, which is an object to be polished, is polished by the polishing apparatus shown in FIGS. 1 and 2. The spectrum of the reflected light is generated each time the polishing table 3 makes one rotation during polishing of the
25 workpiece W.

In step 104, the spectrum processor 30 calculates the index value indicating the similarity between the spectrum of the reflected light from the workpiece W and the interface spectrum each time the spectrum is generated.

In step 105, the spectrum processor 30 determines a polishing endpoint at which the

index value is maximized or minimized.

In step 106, the spectrum processor 30 instructs the operation controller 9 to end polishing of the workpiece W.

[0044] Next, an embodiment of determining the interface spectrum will be described. The interface spectrum is one of the plurality of spectra of reflected light from the reference workpiece generated during polishing of the reference workpiece. The reference workpiece has the same surface structure as the workpiece W. Specifically, as shown in FIG. 3, when the workpiece W has a surface structure including the first film 101 and the second film 102 underlying the first film 101, the reference workpiece also has a surface structure including the first film 101 and the second film 102 underlying the first film 101. The reference workpiece is polished by the polishing apparatus shown in FIGS. 1 and 2 under the same polishing conditions as those for the workpiece W. The polishing conditions include the rotation speed of the polishing table 3, the rotation speed of the polishing head 1, the pressing force of the polishing head 1, and the polishing liquid used.

[0045] During polishing of the reference workpiece, as well as polishing of the workpiece W, the optical sensor head 25 irradiates the reference workpiece with the light each time the polishing table 3 makes one rotation, and the spectrum processor 30 generates the spectrum of the reflected light from the reference workpiece. From the polishing start to the polishing end of the reference workpiece, the plurality of spectra of the reflected light from the reference workpiece are generated.

[0046] The spectrum processor 30 determines the interface spectrum from among the plurality of spectra of the reflected light from the reference workpiece. The interface spectrum is a spectrum of the light reflected from the reference workpiece when the first film of the reference workpiece is removed and the second film is exposed during polishing of the reference workpiece. As a method for determining the interface spectrum from the plurality of spectra generated during polishing of the reference workpiece, a known technology, such as a torque monitoring method or a spectrum monitoring method, can be used.

[0047] The torque monitoring method monitors an electric current (hereinafter referred to

as torque current) supplied to the table motor 6 during polishing of the reference workpiece, and detects a polishing endpoint which is a point in time when the torque current varies across a threshold value. The spectrum monitoring method obtains a cumulative amount of change in spectrum of reflected light from the reference workpiece during polishing of the reference workpiece, and detects a polishing endpoint which is a point in time when the cumulative amount of change in spectrum varies across a certain threshold value. In addition to such known technologies, the interface spectrum may be determined in consideration of a result of judgment on a change in the torque current or a change in the cumulative amount of change in spectrum by an operator.

[0048] In another embodiment, the interface spectrum is determined by an interface-spectrum determination process described below, instead of the technology described above. FIG. 9 is a flowchart explaining an embodiment of the interface-spectrum determination process.

[0049] In step 201, the spectrum processor 30 generates a theoretical interface spectrum of light reflected from the reference workpiece when the first film of the reference workpiece is removed and the second film is exposed. FIG. 10 is a diagram showing an example of the theoretical interface spectrum. The theoretical interface spectrum is generated by light reflection simulation using optical coefficients, such as refractive index of light of the second film, absorption rate of light of the second film, and thickness of the second film.

[0050] In step 202, the spectrum processor 30 generates a plurality of spectra of reflected light from the reference workpiece while the reference workpiece is polished by the polishing apparatus shown in FIGS. 1 and 2.

In step 203, the spectrum processor 30 calculates an index value indicating similarity between each of the plurality of spectra of the reflected light from the reference workpiece and the theoretical interface spectrum. This index value is of the same type as the index value described above indicating the similarity between the spectrum of the reflected light from the workpiece W and the interface spectrum, and is calculated in the same manner. FIG. 11 is a schematic diagram explaining the step 203.

[0051] In step 204, the spectrum processor 30 selects a spectrum at which the index value

calculated in the step 203 is maximized or minimized from among the plurality of spectra obtained in the step 202. Selection of the spectrum at which the index value is maximized or minimized is performed after polishing of the reference workpiece is terminated.

In step 205, the spectrum processor 30 designates the selected spectrum as the interface spectrum. The spectrum processor 30 stores the designated interface spectrum in the memory 30a.

[0052] The interface spectrum determined in this manner is used for detection (or determination) of the polishing endpoint of the workpiece W described with reference to FIG. 8.

[0053] 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 described herein but is to be accorded the widest scope as defined by limitation of the claims.

What is claimed is:

1. A polishing method comprising:

supplying a polishing liquid onto a polishing pad on a polishing table while rotating
5 the polishing table;

polishing a workpiece in the presence of the polishing liquid by pressing the
workpiece against the polishing pad;

irradiating the workpiece with light each time the polishing table makes one rotation,
and generating a spectrum of reflected light from the workpiece;

10 calculating an index value indicating similarity between the spectrum of the
reflected light and an interface spectrum, the interface spectrum being a spectrum of
reflected light from a reference workpiece generated when a first film is removed and a
second film underlying the first film is exposed during polishing of the reference workpiece;
and

15 determining a polishing endpoint at which the index value is maximized or
minimized.

2. The polishing method according to claim 1, wherein the index value comprises a
plurality of index values calculated according to different calculation algorithms, and

20 the polishing endpoint is a point in time when at least one of the plurality of index
values is maximized or minimized.

3. The polishing method according to claim 2, wherein the polishing endpoint is a
point in time when any one of the plurality of index values is first maximized or minimized.

25 4. The polishing method according to claim 2, wherein the polishing endpoint is a
point in time when all of the plurality of index values are maximized or minimized.

5. The polishing method according to claim 1, wherein the reference workpiece has

the same surface structure as that of the workpiece.

6. The polishing method according to claim 1, wherein polishing conditions for the reference workpiece are the same as polishing conditions for the workpiece.

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7. The polishing method according to claim 1, wherein the interface spectrum is obtained in advance by an interface-spectrum acquisition process before polishing of the workpiece, and

the interface-spectrum acquisition process includes:

10 generating a theoretical interface spectrum of light reflected from the reference workpiece when the first film is removed and the second film is exposed;

 generating a plurality of spectra of reflected light from the reference workpiece while polishing the reference workpiece;

15 calculating an index value indicating similarity between each of the plurality of spectra and the theoretical interface spectrum;

 selecting a spectrum at which the index value is maximized or minimized from among the plurality of spectra; and

 designating the selected spectrum as the interface spectrum.

20 8. A polishing apparatus comprising:

 a polishing table configured to support a polishing pad;

 a table motor configured to rotate the polishing table;

 a polishing-liquid supply nozzle configured to supply a polishing liquid onto the polishing pad;

25 a polishing head configured to polish a workpiece in the presence of the polishing liquid by pressing the workpiece against the polishing pad; and

 an optical system configured to irradiate the workpiece with light each time the polishing table makes one rotation, and generate a spectrum of reflected light from the workpiece,

wherein the optical system is configured to:

calculate an index value indicating similarity between the spectrum of the reflected light and an interface spectrum, the interface spectrum being a spectrum of reflected light from a reference workpiece generated when a first film is removed and a second film underlying the first film is exposed during polishing of the reference workpiece;
and

determine a polishing endpoint at which the index value is maximized or minimized.

9. The polishing apparatus according to claim 8, wherein the optical system is configured to:

calculate a plurality of index values according to different calculation algorithms;
and

determine the polishing endpoint at which at least one of the plurality of index values is maximized or minimized.

10. The polishing apparatus according to claim 9, wherein the optical system is configured to determine the polishing endpoint at which any one of the plurality of index values is first maximized or minimized.

11. The polishing apparatus according to claim 9, wherein the optical system is configured to determine the polishing endpoint at which all of the plurality of index values are maximized or minimized.