

POLISHING APPARATUS AND METHOD FOR CONTROLLING POLISHING APPARATUS

TECHNICAL FIELD

[0001] The present invention relates to a polishing apparatus and a method for controlling a polishing apparatus.

BACKGROUND ART

[0002] As a result of polishing of a substrate or the like, which is an object of polishing, by a polishing apparatus, abrasive grains and polishing debris adhere to a surface of a polishing pad; and, further, polishing performance is degraded due to change in the state of the surface of the polishing pad. For recovering the state of a surface of a polishing pad, a dressing process for the polishing pad is performed by using a dressing apparatus. Traditionally, regarding timing when dressing is to be performed, dressing is performed every time when polishing of a predetermined number of substrates is completed (for example, refer to Patent Literature 1).

CITATION LIST

PATENT LITERATURE

[0003] PTL 1: Japanese Patent Application Public Disclosure No. 2022-112194

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0004] In the case that timing of dressing is set in a conventional manner, there may be a case wherein the throughput of a polishing apparatus is lowered as a result of performing of a dressing process. Further, there may be a case wherein a polishing pad is excessively consumed due to dressing. Accordingly, there is a need for control of a polishing apparatus to make it perform dressing at appropriate timing.

SOLUTION TO PROBLEM

[0005] According to an embodiment, a polishing apparatus is provided, and the polishing apparatus comprises: one or multiple polishing units; one or multiple functional units for

performing preprocessing or postprocessing of polishing; one or multiple transfer units for carrying, at least between the polishing unit and the functional unit, an object of polishing; and a controller for performing control to make the polishing unit(s), the functional unit(s), and the transfer unit(s) operate in accordance with a predetermined operation schedule for performing polishing of the object of polishing, wherein the operation schedule comprises multiple free time slots during that the polishing unit(s) is(are) not allowed to perform processing due to restriction relating to relationship between operation of the polishing unit(s), operation of the functional unit(s), and operation of the transfer unit(s): wherein each of the one or multiple polishing units comprises a polishing pad constructed to be pressed against the object of polishing when the object of polishing is polished, a measurement device for measuring a state of a polishing surface of the polishing pad, and a dressing device constructed to apply a dressing process to the polishing pad: and wherein the controller is constructed to determine, based on the state of the polishing surface of the polishing pad measured by the measurement device, estimated timing when the degree of polishing capability of the polishing pad is expected to be fallen below a threshold level; identify, from the multiple free time slots in the operation schedule, a free time slot positioned just before the estimated timing; and make the dressing device perform the dressing process applied to the polishing pad in the identified free time slot.

[0006] According to an embodiment, a polishing apparatus is provided, and the polishing apparatus comprises: one or multiple polishing units; one or multiple functional units for performing preprocessing or postprocessing of polishing; one or multiple transfer units for carrying, at least between the polishing unit and the functional unit, an object of polishing; and a controller for performing control to make the polishing unit(s), the functional unit(s), and the transfer unit(s) operate in accordance with a predetermined operation schedule for performing polishing of the object of polishing, wherein the operation schedule comprises multiple free time slots during that the polishing unit(s) is(are) not allowed to perform processing due to restriction relating to relationship between operation of the polishing unit(s), operation of the functional unit(s), and operation of the transfer unit(s): wherein

each of the one or multiple polishing units comprises a polishing pad constructed to be pressed against the object of polishing when the object of polishing is polished, and a dressing device constructed to apply a dressing process to the polishing pad: and wherein the controller is constructed to make the dressing device(s) perform the dressing process(es) applied to the polishing pad(s) in respective ones of the multiple free time slots.

BRIEF DESCRIPTION OF DRAWINGS

[0007] Fig. 1 is a top view which shows a general construction of a polishing apparatus according to an embodiment of the present invention.

Fig. 2 is a perspective view which shows a construction of a polishing unit according to an embodiment.

Fig. 3 is a side view which schematically shows the polishing unit in Fig. 2.

Fig. 4 is a flowchart which shows an example of a flow of a process performed by a controller in a polishing apparatus.

Fig. 5 shows an example of an operation schedule for controlling a polishing apparatus.

Fig. 6 is a graph which shows an example of temporal change in a pad-state index value of a polishing pad, in a specific polishing unit in a polishing apparatus.

Fig. 7 is a flowchart which shows an example flow of control performed in a polishing apparatus according to an embodiment of the present invention.

Fig. 8 shows an example operation schedule, which is used in a present embodiment, for controlling a polishing apparatus.

Fig. 9 is a graph which shows an example of temporal change in a pad-state index value relating to a specific polishing unit in a polishing apparatus in the present embodiment.

Fig. 10 shows an example of temporal change in a wavelength composition ratio in a polishing unit, in the case that dressing is performed in a free time slot TS303 according to controlling of the present embodiment.

DESCRIPTION OF EMBODIMENTS

[0008] In the following description, embodiments of the present invention will be explained with reference to the figures.

[0009] Fig. 1 is a top view which shows a general construction of a polishing apparatus 10 according to an embodiment of the present invention. The polishing apparatus 10 may be a CMP (Chemical Mechanical Polishing) apparatus, for example. A CMP apparatus is used for polishing a semiconductor substrate, a glass substrate, a metal thin film or a semiconductor thin film formed on the semiconductor substrate or the glass substrate, or the like. As shown in Fig. 1, the CMP apparatus (i.e., the polishing apparatus) 10 comprises a load/unload unit 100, a first transfer unit 200, a second transfer unit 300, a third transfer unit 400, one or multiple polishing units 500, a wafer station 600, one or multiple cleaning units 700, and a controller 800.

[0010] The load/unload unit 100 is a module for carrying a substrate, which is an object of polishing, into the polishing apparatus 10, and carrying the substrate from the polishing apparatus 10. For example, cassettes (which are not shown in the figure), such as FOUPs or the like in which multiple substrates which have not yet been polished are stored, are loaded in the load/unload unit 100; and the substrates, which are taken out of the cassettes, are carried into the polishing apparatus 10. Further, polished substrates are returned to the cassettes to be stored therein, and the cassettes are removed from the polishing apparatus 10. In this regard, it should be reminded that, although the polishing apparatus 10 is provided with four load/unload units 100 in the example shown in Fig. 1, it is possible to determine the number of load/unload units 100 optionally.

[0011] The first transfer unit 200 is constructed in such a manner that it is arranged in a position adjacent to the load/unload unit 100 and the second transfer unit 300; operates to take a substrate, which has not yet been polished, out of a cassette loaded in the load/unload unit 100 and deliver the substrate to the second transfer unit 300; and operates to receive the polished substrate from the second transfer unit 300 and store the substrate into the cassette loaded in the load/unload unit 100.

[0012] The second transfer unit 300 is arranged in a position that is adjacent to the first transfer unit 200, and is also adjacent to respective polishing units in the one or multiple polishing units 500 and the wafer station 600. As shown in Fig. 1, the second transfer unit

300 may be arranged in a row direction of the multiple polishing units 500 which have been arranged in a row in a direction. The second transfer unit 300 is constructed in such a manner that it operates to receive a substrate, which has not yet been polished, from the first transfer unit 200; and deliver the substrate to a predetermined polishing unit in the one or multiple polishing units 500 to store it in the polishing unit. Further, the second transfer unit 300 is constructed in such a manner that it operates to take the substrate, with respect to which a polishing process applied thereto by the polishing unit 500 has been completed, out of the polishing unit 500: and deliver the substrate to the wafer station 600 so as to make the wafer station 600 receive the substrate.

[0013] The one or multiple polishing units 500 are units for polishing substrates which are objects of polishing, and details of the polishing units will be explained later. In this regard, it should be reminded that, although the polishing apparatus 10 is provided with four polishing units 500 in the example shown in Fig. 1, it is possible to determine the number of polishing units 500 optionally.

[0014] The wafer station 600 is a unit which is constructed to temporarily hold a substrate polished in the polishing unit 500. In this regard, the wafer station 600 may be constructed as a part of the second transfer unit 300 or the third transfer unit 400.

[0015] The third transfer unit 400 is arranged in a position that is adjacent to the wafer station 600 and respective cleaning units in the one or multiple cleaning units 700. As shown in Fig. 1, the third transfer unit 400 may be arranged in a row direction of the multiple cleaning units 700 which have been arranged in a row in a direction. The third transfer unit 400 is constructed in such a manner that it operates to deliver a substrate, which has temporarily been held in the wafer station 600, to a predetermined cleaning unit in the one or multiple cleaning units 700 to store it in the cleaning unit. Further, the third transfer unit 400 is constructed in such a manner that it operates to take the substrate, with respect to which a washing process applied thereto by the cleaning unit 700 has been completed, out of the cleaning unit 700; and return the substrate to the wafer station 600. The third transfer unit 400 may be arranged and constructed in such a manner that it delivers a washed substrate

to the first transfer unit 200, instead of returning the washed substrate to the wafer station 600. Further, the third transfer unit 400 may be constructed in such a manner that, after taking a substrate, with respect to which a washing process applied thereto by a specific cleaning unit 700 has been completed, out of the cleaning unit 700, it operates to deliver the substrate, for example, to a different cleaning unit 700 for applying a higher-cleanliness cleaning process to the substrate.

[0016] The one or multiple cleaning units 700 are units for washing polished substrates for washing away a polishing slurry, polishing debris, and so on which are adhered to a surface of a substrate during a polishing process performed in the polishing unit 500. Respective cleaning units in the one or multiple cleaning units 700 may be constructed, for example, in such a manner that the cleaning units perform washing processes by using different cleaning liquids and different washing conditions, respectively, for applying the respective cleaning processes to a single substrate in a stepwise manner, wherein a degree of cleanliness that is to be achieved by a cleaning process is different from degrees of cleanliness that are to be achieved by other cleaning processes. In this regard, it should be reminded that, although the polishing apparatus 10 is provided with four cleaning units 700 in the example shown in Fig. 1, it is possible to determine the number of cleaning units 700 optionally.

[0017] The cleaning unit 700 is an example of a functional unit which performs postprocessing applied to a substrate polished by the polishing unit 500 (that is, washing is an example of postprocessing). The polishing apparatus 10 may be constructed to further include, in addition to the cleaning unit 700, a different functional unit which is constructed to perform a kind of postprocessing that is different from washing (for example, a drying unit for drying a washed substrate), and/or a different functional unit which is constructed to perform predetermined preprocessing that is to be applied to a substrate to which a polishing process has not yet been applied (for example, a pre-cleaning unit for washing a substrate which has not yet been polished).

[0018] The controller 800 is a device for controlling operation of each of the above-

explained components in the polishing apparatus 10. The controller 800 may be constructed by using a general computer which comprises a processor and a memory. The memory stores a predetermined program for controlling the polishing apparatus 10, and controlling of respective parts in the polishing apparatus 10 is realized by reading the program from the memory and executing the program by the processor. Details of control performed by the controller 800 will be explained later.

[0019] Next, details of the polishing unit 500 included in the polishing apparatus 10 will be explained. Fig. 2 is a perspective view which shows a construction of the polishing unit 500 according to an embodiment. Fig. 3 is a side view which schematically shows the polishing unit 500 in Fig. 2. In the case that the polishing apparatus 10 comprises multiple polishing units 500, each of the polishing unit 500 may be that having constructions identical with those shown in Figs. 2 and 3. As shown in Fig. 2, the polishing unit 500 comprises a polishing table 350, and a top ring 302 which constitutes a polishing head which holds an object-of-polishing substrate, and functions to press the substrate against a polishing surface on a polishing table 350. The polishing table 350 is connected, via a table shaft 351, to a polishing table rotating motor (which is not shown in the figures) arranged in a position below the table shaft, and is rotatable about the table shaft 351. A polishing pad 352 is attached to a top surface of the polishing table 350, and a surface 352a of the polishing pad 352 constitutes a polishing surface for polishing a substrate.

[0020] A polishing slurry supplying nozzle 354 is arranged in a position above the polishing table 350, and a polishing slurry is supplied to the polishing pad 352 on the polishing table 350 by the polishing slurry supplying nozzle 354. Further, as shown in Fig. 2, a passage 353 for supplying a polishing slurry is formed in the polishing table 350 and the table shaft 351. The passage 353 communicates with an opening 355 on the surface of the polishing table 350. A through hole 357 is formed in the polishing pad 352, in a position corresponding to that of the opening 355 in the polishing table 350; and the polishing slurry passing through the passage 353 is supplied from the opening 355 in the polishing table 350 and the through hole 357 in the polishing pad 352 to the surface of the polishing pad 352.

In this regard, it may be possible to form one or multiple the openings 355 in the polishing table 350 and the through holes 357 in the polishing pad 352. Further, although the positions of the opening 355 in the polishing table 350 and the through hole 357 in the polishing pad 352 can be selected optionally, they are arranged in positions in or close to the center of the polishing table 350 in the embodiment.

[0021] The top ring 302 is connected to a top ring shaft 18, and the top ring shaft 18 is constructed to be moved upward/downward relative to a swinging arm 360 by a vertical motion mechanism 319. Positioning is performed by moving the top ring shaft 18 upward/downward to thereby move the whole top ring 302 upward/downward relative to a swinging arm 360. The top ring shaft 18 is constructed to be rotated by driving a top ring rotating motor which is not shown in the figures. The top ring 302 is constructed to be rotated about the top ring shaft 18 when the top ring shaft 18 is rotated. In this regard, a rotary joint 323 is attached to an upper end of the top ring shaft 18.

[0022] The top ring 302 is constructed to be able to hold, on a bottom surface thereof, an object-of-polishing substrate. The swinging arm 360 is constructed to be able to swing about a support shaft 362. The top ring 302 is movable between a position where a substrate is delivered to/from a transfer unit which is not shown in the figures (for example, the second transfer unit 300 explained in relation to Fig. 1) and a position above the polishing table 350, by moving the swinging arm 360 in a swinging manner. By moving the top ring shaft 18 downward, the top ring 302 can be moved downward to thereby press a substrate against the surface (the polishing surface) 352a of the polishing pad 352. At that time, the top ring 302 and the polishing table 350 are rotated respectively, and the polishing slurry is supplied to the polishing pad 352 from the polishing slurry supplying nozzle 354 arranged in a position above the polishing table 350 and/or the opening 355 formed in the polishing table 350. Thus, a surface of a substrate can be polished by pressing the substrate against the polishing surface 352a of the polishing pad 352. The arm 360 may be fixed in such a manner that the top ring 302 covers the through hole 357 in the polishing pad 352, or the arm 360 may be operated to swing in such a manner that the top ring 302 passes over the center of

the polishing pad 352, during polishing of a substrate.

[0023] The vertical motion mechanism 319 for moving the top ring shaft 18 and the top ring 302 upward and downward comprises a bridge 28 for supporting, via a bearing 321, the top ring shaft 18 in a rotatable manner, a ball screw 32 attached to the bridge 28, a support base 29 supported by support columns 130, and an AC servomotor 38 installed on the support base 29. The support base 29, which supports the servomotor 38, is fixed to the swinging arm 360 via the support columns 130.

[0024] The ball screw 32 comprises a screw shaft 32a which is connected to the servomotor 38, and a nut 32b which is screwed to the screw shaft 32a. The top ring shaft 18 is constructed to be moved upward and downward together with the bridge 28. Thus, when the servomotor 38 is driven, the bridge 28 moves upward and downward via the ball screw 32, and, accordingly, the top ring shaft 18 and the top ring 302 move upward and downward.

[0025] The polishing unit 500 according to an embodiment comprises a dressing unit 356 for performing dressing of the polishing surface 352a of the polishing pad 352. The dressing unit 356 comprises a dresser 50 which is brought into contact with the polishing surface 352a in a sliding manner, a dresser shaft 51 to which the dresser 50 is connected, an air cylinder 53 installed on an upper end of the dresser shaft 51, and a swinging arm 55 which supports the dresser shaft 51 in a rotatable manner. A lower part of the dresser 50 comprises a dressing member 50a, and acicular diamond particles have been adhered to a bottom surface of the dressing member 50a. The air cylinder 53 is positioned on a support base 57 supported by support columns 56, and the support columns 56 are fixed to the swinging arm 55.

[0026] The swinging arm 55 is constructed to be driven by a motor, which is not shown in the figures, to rotate about a support shaft 58. The dresser shaft 51 is constructed to be rotated when a motor which is not shown in the figures is driven; and, when the dresser shaft 51 is rotated, the dresser 50 is rotated about the dresser shaft 51. The air cylinder 53 moves the dresser 50 upward and downward via the dresser shaft 51 to press, with predetermined pressing force, the dresser 50 against the polishing surface 352a of the

polishing pad 352.

[0027] Dressing of the polishing surface 352a of the polishing pad 352 is performed as explained below. The dresser 50 is pressed against the polishing surface 352a by the air cylinder 53, and, at the same time, pure water is supplied to the polishing surface 352a from a pure-water supplying nozzle which is not shown in the figures. In the above state, the dresser 50 is rotated about the dresser shaft 51; and the bottom surface (diamond particles) of the dressing member 50a is brought into contact, in a sliding manner, with the polishing surface 352a which is being rotated, and the swinging arm 55 is also operated to swing on the polishing surface 352a. Thus, the polishing pad 352 is shaven by the dresser 50, and, accordingly, the polishing surface 352a is dressed.

[0028] The polishing unit 500 according to an embodiment further comprises a measurement unit 502 (which is not shown in Fig. 2) for measuring the state of the polishing surface 352a of the polishing pad 352. For example, as shown in Fig. 3, the measurement unit 502 may be arranged in a position above the polishing surface 352a of the polishing pad 352. For example, the measurement unit 502 is constructed to emit measuring light L1 to the polishing pad 352, and detect reflected light L2 reflected from the polishing surface 352a of the polishing pad 352. In an embodiment, the measurement unit 502 may be constructed to supply, to the controller 800, a detection signal of the reflected light L2. The controller 800 is able to identify the state of the polishing surface 352a of the polishing pad 352, based on the detection signal, that is obtained by the measurement unit 502, of the reflected light L2 from the polishing pad 352. For example, based on analysis of intensity or a spatial spectrum of the reflected light L2 from the polishing pad 352, an index value representing the state of the polishing surface 352a of the polishing pad 352 (hereinafter, pad-state index value) may be calculated.

[0029] The pad-state index value may be calculated based on analysis of intensity or a spatial spectrum of the reflected light L2 from the polishing pad 352, wherein the analysis may be that performed by using an appropriate method. For example, a "wavelength composition ratio" disclosed in Japanese Patent Application Public Disclosure No. 2022-

112194 may be used as the pad-state index value. Specifically, from measured reflected light L2, the wavelength composition ratio can be calculated in accordance with following formula (1).

[0030]

[FORMULA 1]

$$\frac{\int_{\xi_1}^{\xi_2} I(\xi) d\xi}{\int_{\xi_3}^{\xi_4} I(\xi) d\xi} \quad (1)$$

[0031] In the present case, $I(\xi)$ represents a spatial spectrum distribution of the reflected light L2 from the polishing pad 352, and ξ represents a reciprocal of a spatial frequency of the reflected light L2. Further, it is supposed that $\xi_3 < \xi_1 < \xi_2 < \xi_4$. The value of the wavelength composition ratio becomes smaller as the roughness of the polishing surface 352a of the polishing pad 352 becomes larger (i.e., as the degree of capability to polish the polishing pad 352 becomes higher). To the contrary, the value of the wavelength composition ratio becomes larger as the smoothness of the polishing surface 352a of the polishing pad 352 becomes larger (i.e., as the degree of the polishing capability of the polishing pad 352 becomes lower due to abrasion). Accordingly, it becomes possible to grasp the state of the polishing surface 352a of the polishing pad 352 (or the degree of the polishing capability of the polishing pad 352), by knowing the value of the wavelength composition ratio.

[0032] It should be reminded that, in place of a wavelength composition ratio such as that explained above, a different appropriate index may be used as the pad-state index value. Further, although a mode wherein the measurement unit 502 performs measurement using an optical technique has been explained in the above description, the measurement unit 502 may be constructed to perform measurement using, for example, an acoustic technique. The measurement unit 502 may be constructed to perform measurement using an optical technique, an acoustic technique, or the other technique, and send a measurement signal or data obtained thereby to the controller 800; and the controller 800 may be constructed to

calculate or determine, based on the measurement signal or the data from the measurement unit 502, a pad-state index value representing the state of the polishing surface 352a of the polishing pad 352. In a different construction, the measurement unit 502 itself (or the polishing unit 500) may be constructed in such a manner that it comprises an arithmetic function (for example, a processor) for calculating, based on the measurement signal or the data, a pad-state index value, and supplies the calculated pad-state index value to the controller 800.

[0033] Fig. 4 is a flowchart which shows an example of a flow of a process performed by the controller 800 in the above-explained polishing apparatus 10. A series of operation steps, that is performed when the polishing apparatus 10 polishes an object of polishing, will be explained with reference to Fig. 4.

[0034] First, in step 402, the controller 800 creates, based on predetermined recipe information, an operation schedule for making each of the transfer units 200, 300, and 400, each of the polishing units 500, and each of the cleaning units 700 in the polishing apparatus 10 operate in an appropriate operation order. In step 404 that follows the above step, the controller 800 controls the respective units in the polishing apparatus 10 in accordance with the created operation schedule.

[0035] The predetermined recipe information used for creating the operation schedule may be that comprising, for example, the number of object-of-polishing substrates which are in a present processing lot and should be polished, a target film thickness of a polished film on an object-of-polishing substrate, material of a film which is to be polished, the expected required length of polishing time for polishing a single substrate, the number of polishing units 500 which are to be operated, polishing operation conditions of each polishing unit 500 (for example, the number of rotations of each of the polishing table 350 and the top ring 302, pressing force applied to the polishing table 350 by the top ring 302, the type and quantity of a polishing slurry that is to be used, and so on), the number of the cleaning units 700 which are to be operated, washing conditions of each cleaning unit 700 (for example, the type of the cleaning liquid, the temperature, the length of washing time, and so on), and so on.

[0036] Fig. 5 shows an example of an operation schedule for controlling the polishing apparatus 10. Specifically, Fig. 5 shows an operation schedule for four object-of-polishing substrates, i.e., the N-th to (N+3)th substrates. The horizontal axis in Fig. 5 represents time, and the vertical direction in Fig. 5 corresponds to different substrates. In the example operation schedule shown in Fig. 5, for example, the N-th object-of-polishing substrate (which is shown in the bottom part in the figure) is carried from the load/unload unit 100 to the second transfer unit 300 by the first transfer unit 200 in a time slot TS101, and carried to a predetermined polishing unit (this will be referred to as a polishing unit A) in the one or multiple polishing units 500 by the second transfer unit 300 in a time slot TS102. Next, in a time slot TS103, regular dressing for the polishing pad 352 is performed by the dressing unit 356. The regular dressing may be set, for example, based on accumulated time of use of the polishing pad 352 which is presently used.

[0037] Thereafter, in a time slot TS104, polishing of the N-th object-of-polishing substrate is performed by the polishing unit A. In this regard, at the time when polishing of the N-th object-of-polishing substrate is completed, the second transfer unit 300 is carrying the (N+1)th object-of-polishing substrate to the wafer station 600 (refer to a time slot TS204 relating to the (N+1)th substrate); so that the N-th object-of-polishing substrate is forced to stay in the polishing unit A in a next time slot TS105. In a time slot TS106 during that the wafer station 600 is allowed to be used, the N-th object-of-polishing substrate is taken out of the polishing unit A and carried to the wafer station 600 by the second transfer unit 300, and temporarily held in the wafer station in a time slot TS107.

[0038] Next, in a time slot TS108, the N-th object-of-polishing substrate is carried from the wafer station 600 to a cleaning unit (this will be referred to as a cleaning unit A) in the one or multiple cleaning units 700 by the third transfer unit 400, and, in a time slot TS109, washing of the N-th object-of-polishing substrate is performed in the cleaning unit A. Further, in a time slot TS110, the N-th object-of-polishing substrate is carried from the cleaning unit A to a different cleaning unit B by the third transfer unit 400, and, in a time slot TS111, washing of the second time for the above substrate is performed in the cleaning unit

B. Thereafter, processes similar to the above processes are further preformed in time slots TS112 and TS113 to apply washing of the third time to the above substrate in the cleaning unit C. Finally, in a time slot TS114, N-th object-of-polishing substrate is returned to the load/unload unit 100 by the first transfer unit 200.

[0039] With respect to the (N+1)th object-of-polishing substrate, operation steps, that are similar to those explained above, of the respective components in the polishing apparatus 10 are performed similarly in time slots TS201-TS212. In this regard, it is supposed that the polishing unit which polishes the (N+1)th object-of-polishing substrate is a polishing unit B (refer to a time slot TS203) which is different from the polishing unit A which polishes the N-th object-of-polishing substrate. It should be reminded that the first transfer unit 200 is allowed to start carrying of the (N+1)th object-of-polishing substrate held in the load/unload station 100, after the N-th object-of-polishing substrate, which is in a position in the processing order just before that of the (N+1)th object-of-polishing substrate, is carried to the second transfer unit 300 by the first transfer unit 200; accordingly, regarding a time slot TS201 during that the first transfer unit 200 carries the (N+1)th object-of-polishing substrate, timing when the time slot TS201 starts is later than timing when time slot TS101 (or TS 102) relating to the N-th object-of-polishing substrate ends.

[0040] In relation to the (N+2)th and (N+3)th object-of-polishing substrates, operation steps of the respective components in the polishing apparatus 10 are performed, in a manner similar to that explained above, in accordance with the respective time slots shown in Fig. 5. In this regard, it is supposed that the (N+2)th substrate is polished by the polishing unit A, and the (N+3)th substrate is polished by the polishing unit B (refer to a time slot TS304 and a time slot TS403).

[0041] In this regard, at the time of a time slot TS302 during that the (N+2)th object-of-polishing substrate is carried to the polishing unit A, the polishing unit A is still performing processing of a substrate which is in a position in the processing order just before that of the (N+2)th substrate (i.e., the N-th substrate); accordingly, the (N+2)th object-of-polishing substrate is forced to stay in the first transfer unit 200 during a time slot TS303 that follows

the present time slot TS302 (i.e., until polishing of the N-th substrate in the polishing unit A is completed). The above delay in operation has occurred due to insertion of the time slot TS103, that is set for performing regular dressing of the polishing pad 352, to a position before the time slot for polishing the N-th object-of-polishing substrate by the polishing unit A, and resultant timing shift that delays timing to start processing of the N-th object-of-polishing substrate by the polishing unit A. Further, as a result that the (N+2)th object-of-polishing substrate is forced to stay in the first transfer unit 200 during the time slot TS303, timing to start a time slot TS401, during that the first transfer unit 200 carries a next substrate, i.e., the (N+3)th substrate, from the load/unload unit 100, is delayed until the end of the time slot TS303.

[0042] As explained above, in the case that dressing of the polishing pad 352 is performed at regular timing, operation of some units in the polishing apparatus 10 is delayed, and, accordingly, the throughput of the polishing apparatus (the number of substrates processed per unit time) may be lowered. Further, consumption of the polishing pad 352 may be advanced for the reasons that will be explained next.

[0043] Fig. 6 is a graph which shows an example of temporal change in a pad-state index value (for example, a wavelength composition ratio) of the polishing pad 352, in a specific polishing unit 500 (for example, the polishing unit A) in the polishing apparatus 10. Fig. 6 also shows, along with the graph, the example operation schedule shown in Fig. 5 which has a time scale identical with that of the graph, and the temporal change in the pad-state index value represents that observed when the polishing apparatus 10 is operated in accordance with the example operation schedule in Fig. 5. Further, a dotted line 602 which shows an upper limit value and a dotted line 604 which shows a lower limit value in an appropriate range of the pad-state index values are also depicted in the graph in Fig. 6. As explained above, regarding the wavelength composition ratio, the value thereof increases as abrasion of the polishing surface 352a advances due to use of the polishing pad 352, and decreases when the roughness of the polishing surface 352a is recovered as a result of dressing of the polishing pad 352. Fig. 6 shows a manner that the value of the wavelength composition

ratio decreases in the time slot TS103, wherein the slot has been set for performing dressing of the polishing pad 352 by the dressing unit 356. In this regard, in the example in Fig. 6, a margin still remains between the value of the wavelength composition ratio and the upper limit value of the appropriate range (the dotted line 602) at the time of a start of the time slot TS103 (i.e., the polishing pad 352 still has sufficient polishing capability); so that polishing of a substrate can be performed without performing dressing of the polishing pad 352. That is, the operation schedule in Fig. 5 is that wherein dressing of the polishing pad 352 is scheduled to be performed at unnecessarily early timing, and, accordingly, the number of times that dressing is performed increases; and, accordingly, it is worried that there may be a case wherein the polishing pad 352 reaches its life in an earlier stage.

[0044] Fig. 7 is a flowchart which shows an example flow of control performed in the polishing apparatus 10 according to an embodiment of the present invention, which is able to make the polishing apparatus 10 perform operation more efficiently in view of the above points. An example of improved operation of the polishing apparatus 10 will be explained with reference to Fig. 7.

[0045] First, in step 702, the controller 800 creates, based on predetermined recipe information, an operation schedule for making each of the transfer units 200, 300, and 400, each of the polishing units 500, and each of the cleaning units 700 in the polishing apparatus 10 operate in an appropriate operation order. In this regard, the created operation schedule is that different from the above-explained operation schedule in Fig. 5, and does not include a time slot for applying dressing to the polishing pad 352. In step 704 that follows the above step, the controller 800 starts controlling of operation of the respective units in the polishing apparatus 10 in accordance with the operation schedule created in step 702.

[0046] Fig. 8 shows an example operation schedule, which is created and used in the present embodiment, for controlling the polishing apparatus 10. The operation schedule in Fig. 8 has been described in accordance with a legend similar to that relating to the operation schedule in Fig. 5. Thus, for avoiding complication in explanation, tangible explanation relating to the operation schedule in Fig. 8 will be omitted. In this regard, it should be

reminded that the operation schedule in Fig. 8 includes some "free time slots." A free time slot is a time slot during that a specific polishing unit 500 is not allowed to perform processing, due to restriction relating to relationship between operation states of respective units (for example, the polishing units 500, cleaning units 700, and transfer units 200, 300, and 400) in the polishing apparatus 10. For example, in the example operation schedule in Fig. 8, a time slot TS303 relating to the (N+2)th object-of-polishing substrate has been set as a free time slot for the reasons stated below. That is, at the time of a time slot TS302 that is set for carrying the (N+2)th object-of-polishing substrate to the polishing unit A, the polishing unit A is still performing processing of the N-th substrate which is in a position in the processing order just before that of the (N+2)th substrate (this state is similar to that in the example in Fig. 5). The time when the N-th substrate is taken out of the polishing unit A by the second transfer unit 300 is in a time slot TS105; and, accordingly, the schedule has been created in such a manner that, before taking the N-th substrate out of the polishing unit A, the second transfer unit 300 carries the (N+3)th object-of-polishing substrate during a time slot TS402. Accordingly, after the time slot TS302, a start of a polishing process that is to be applied to the (N+2)th substrate in the polishing unit A (the time slot TS304) is deferred, until the polishing unit A completes polishing of the N-th substrate (the time slot TS103) and the second transfer unit 300 carries the (N+3)th substrate in the time slot TS402, and, further, takes the N-th substrate out of the polishing unit A in the time slot TS105. Thus, the free time slot TS303, during that the polishing unit A is not allowed to perform operation, exists in the example operation schedule in Fig. 8.

[0047] The flowchart will be referred to again. Next, in step 706, i.e., after a start of controlling of the polishing apparatus 10, the controller 800 obtains, from the measurement unit 502 in each polishing unit 500, the state of the polishing surface 352a of the polishing pad 352 in the polishing unit 500. For example, the controller 800 obtains, from each measurement unit 502, a measurement signal representing the state of the polishing surface 352a of the polishing pad 352. In step 708 that follows the above step, the controller 800 calculates, based on the measurement signal obtained from each measurement unit 502, a

pad-state index value with respect to the polishing pad 352 in each polishing unit 500. An example mode of calculation of the pad-state index value is similar to that explained above (for example, refer to formula (1) for calculating a wavelength composition ratio).

[0048] Next, in step 710, the controller 800 tracks temporal change in the pad-state index value of each of the polishing units 500, and estimates timing when the value of the pad-state index value changes to that out of a predetermined appropriate range. As explained above, the value of the wavelength composition ratio increases as abrasion of the polishing surface 352a advances due to use of the polishing pad 352. That is, increase in the value of the wavelength composition ratio corresponds to decrease in the degree of the polishing capability of the polishing pad 352. For example, with respect to each polishing unit 500, the controller 800 tracks temporal change in the value of the wavelength composition ratio, and estimates timing when the degree of the polishing capability of the polishing pad 352 decreases below a predetermined threshold level.

[0049] Fig. 9 is a graph which shows an example of temporal change in a pad-state index value (for example, a wavelength composition ratio) relating to a specific polishing unit 500 (for example, the polishing unit A) in the polishing apparatus 10 in the present embodiment. Fig. 9 also shows, along with the graph, the example operation schedule shown in Fig. 8 which has a time scale identical with that of the graph. An upper limit value and a lower limit value of an appropriate range of the pad-state index values are represented by a dotted line 902 and a dotted line 904, respectively. In Fig. 9, the value of the pad-state index value increases over time (i.e., as the length of operation time of the polishing pad 352 increases). For example, at an appropriate point in time before an end of the time slot TS302 that relates to the (N+2)th object-of-polishing substrate, the controller 800 estimate, based on the temporal change in the wavelength composition ratio observed until the above point in time, the value of the wavelength composition ratio at a point(s) in time after the above point in time (for example, by performing extrapolation), and identifies timing t_x when the estimated value of the wavelength composition ratio exceeds the upper limit value (the dotted line 902).

[0050] Next, in step 712, with respect to each polishing unit 500, the controller 800

searches the operation schedule for a free time slot that is positioned just before the identified timing estimated in step 710 (for example, the timing tx). In step 714 that follows the above step, the controller 800 designates the free time slot just before the above identified timing as a dressing performing slot, and performs control to apply, with respect to each polishing unit 500, dressing to the polishing pad 352 in the dressing performing slot. For example, in the example in Fig. 9, the timing tx is identified (estimated) based on the wavelength composition ratio relating to the polishing unit A as explained above. In terms of the polishing unit A, a free time slot, that is positioned just before the timing tx, is the time slot TS303. Accordingly, the free time slot TS303 is designated as a dressing performing slot for the polishing unit A, and the dressing unit 356 in the polishing unit A is controlled to perform dressing of the polishing pad 352 in the free time slot TS303. Timing to perform dressing in each of other polishing units 500 (for example, the polishing unit B) is also controlled in a manner similar to that explained above.

[0051] Fig. 10 shows an example of temporal change in a wavelength composition ratio in the polishing unit A, in the case that dressing is performed in the free time slot TS303 according to the above control. Since dressing is performed after the pad-state index value (the wavelength composition ratio) has closely approached the limit of the appropriate range in the example in Fig. 10, the polishing capability of the polishing pad 352 can be used more effectively compared with the case of the above-explained example in Fig. 6 (i.e., the polishing pad can be used until the degree of the polishing capability becomes that corresponding or close to the predetermined allowable level); and accordingly, it becomes possible to prevent dressing of the polishing pad 352 from being performed at unnecessarily early timing, and extend the life of the polishing pad 352. Further, since dressing is performed by using a "free time slot" in the control according to the present embodiment, dressing of the polishing pad 352 can be performed without causing delay in operation of other units in the polishing apparatus 10, and, accordingly, lowering of throughput of the polishing apparatus 10 can be prevented effectively.

[0052] In a different embodiment, the controller 800 may perform control in such a

manner that dressing of the polishing pad 352 is performed in any free time slot (for example, all free time slots). In such a case, although the total number of times of dressing increases, excessive consumption of the polishing pad 352 due to dressing can be prevented and optimization of the operation schedule of the whole polishing apparatus 10 can be achieved, by setting the length of time of each dressing process to be short.

[0053] In the above description, embodiments of the present invention have been explained based on some examples; and, in this regard, the above explained embodiments of the present invention are those used for facilitating understanding of the present invention, and are not those used for limiting the present invention. It is obvious that the present invention can be changed or modified without departing from the scope of the gist thereof, and that the present invention includes equivalents thereof. Further, it is possible to arbitrarily combine components or omit a component(s) disclosed in the claims and the specification, within the scope that at least part of the above-stated problems can be solved or within the scope that at least part of advantageous effect can be obtained.

REFERENCE SIGNS LIST

[0054] 10 Polishing apparatus

100 Load/unload unit

200 First transfer unit

300 Second transfer unit

400 Third transfer unit

500 Polishing unit

600 Wafer station

700 Cleaning unit

800 Controller

352 Polishing pad

356 Dressing unit

502 Measurement unit

WHAT IS CLAIMED IS:

1. A polishing apparatus comprising:
 - one or multiple polishing units,
 - one or multiple functional units for performing preprocessing or postprocessing of polishing,
 - one or multiple transfer units for carrying, at least between the polishing unit and the functional unit, an object of polishing, and
 - a controller for performing control to make the polishing unit, the functional unit, and the transfer unit operate in accordance with a predetermined operation schedule for performing polishing of the object of polishing, wherein the operation schedule comprises multiple free time slots during that the polishing unit is not allowed to perform processing due to restriction relating to relationship between operation of the polishing unit, operation of the functional unit, and operation of the transfer unit;
 - wherein
 - each of the one or multiple polishing units comprises
 - a polishing pad constructed to be pressed against the object of polishing when the object of polishing is polished,
 - a measurement device for measuring a state of a polishing surface of the polishing pad, and
 - a dressing device constructed to apply a dressing process to the polishing pad;
 - and
 - wherein
 - the controller is constructed to
 - determine, based on the state of the polishing surface of the polishing pad measured by the measurement device, estimated timing when the degree of polishing capability of the polishing pad is expected to be fallen below a threshold level,
 - identify, from the multiple free time slots in the operation schedule, a free time

slot positioned just before the estimated timing, and

make the dressing device perform the dressing process applied to the polishing pad in the identified free time slot.

2. The polishing apparatus as recited in Claim 1, wherein determination of the timing is based on extrapolation applied to an index representing the state of the polishing surface of the polishing pad.

3. The polishing apparatus as recited in Claim 1, wherein the controller is constructed to make, with respect to each of the multiple free time slots in the operation schedule and by performing extrapolation, an estimate as to whether the degree of polishing capability of the polishing pad falls below the threshold level; and, if the estimate shows that the degree of polishing capability falls below the threshold level, make the dressing device apply the dressing process to the polishing pad in the free time slot.

4. The polishing apparatus as recited in any one of Claims 1-3, wherein the functional unit comprises a cleaning unit for washing the object of polishing after it is polished by the polishing unit.

5. The polishing apparatus as recited in Claim 1, wherein the controller is further constructed to create the predetermined operation schedule based on predetermined recipe information.

6. A polishing apparatus comprising:

one or multiple polishing units,

one or multiple functional units for performing preprocessing or postprocessing of polishing,

one or multiple transfer units for carrying, at least between the polishing unit and the functional unit, an object of polishing, and

a controller for performing control to make the polishing unit, the functional unit, and the transfer unit operate in accordance with a predetermined operation schedule for performing polishing of the object of polishing, wherein the operation schedule comprises multiple free time slots during that the polishing unit is not allowed to perform processing

due to restriction relating to relationship between operation of the polishing unit, operation of the functional unit, and operation of the transfer unit;

wherein

each of the one or multiple polishing units comprises

a polishing pad constructed to be pressed against the object of polishing when the object of polishing is polished, and

a dressing device constructed to apply a dressing process to the polishing pad;

and

wherein

the controller is constructed to make the dressing device perform the dressing process applied to the polishing pad in each of the multiple free time slots.

7. A method for controlling a polishing apparatus, wherein the polishing apparatus comprises:

one or multiple polishing units,

one or multiple functional units for performing preprocessing or postprocessing of polishing,

one or multiple transfer units for carrying, at least between the polishing unit and the functional unit, an object of polishing, and

a controller for performing control to make the polishing unit, the functional unit, and the transfer unit operate in accordance with a predetermined operation schedule for performing polishing of the object of polishing, wherein the operation schedule comprises multiple free time slots during that the polishing unit is not allowed to perform processing due to restriction relating to relationship between operation of the polishing unit, operation of the functional unit, and operation of the transfer unit;

wherein

each of the one or multiple polishing units comprises

a polishing pad constructed to be pressed against the object of polishing when the object of polishing is polished,

a measurement device for measuring a state of a polishing surface of the polishing pad, and

a dressing device constructed to apply a dressing process to the polishing pad:
and

the method comprises steps for

determining, by the controller and based on the state of the polishing surface of the polishing pad measured by the measurement device, estimated timing when the degree of polishing capability of the polishing pad is expected to be fallen below a threshold level,

identifying, by the controller and from the multiple free time slots in the operation schedule, a free time slot positioned just before the estimated timing, and

making, by the controller, the dressing device perform the dressing process applied to the polishing pad in the identified free time slot.

8. A method for controlling a polishing apparatus, wherein the polishing apparatus comprises:

one or multiple polishing units,

one or multiple functional units for performing preprocessing or postprocessing of polishing,

one or multiple transfer units for carrying, at least between the polishing unit and the functional unit, an object of polishing, and

a controller for performing control to make the polishing unit, the functional unit, and the transfer unit operate in accordance with a predetermined operation schedule for performing polishing of the object of polishing, wherein the operation schedule comprises multiple free time slots during that the polishing unit is not allowed to perform processing due to restriction relating to relationship between operation of the polishing unit, operation of the functional unit, and operation of the transfer unit;

wherein

each of the one or multiple polishing units comprises

a polishing pad constructed to be pressed against the object of polishing when the

object of polishing is polished, and

a dressing device constructed to apply a dressing process to the polishing pad:

and

the method comprises a step performed by the controller for making the dressing device perform the dressing process applied to the polishing pad in each of the multiple free time slots.