

DESCRIPTION

Title of Invention

DRESSING-CONDITION DETERMINING APPARATUS AND DRESSING-
CONDITION DETERMINING METHOD

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Technical Field

[0001] The present invention relates to a technique for determining a dressing condition for dressing a polishing pad used for polishing a workpiece, such as a wafer, a substrate, or a panel.

10 Background Art

[0002] Chemical mechanical polishing (hereinafter referred to as CMP) is a process of polishing a workpiece (for example, a wafer, a substrate, or a panel) by bringing the workpiece into sliding contact with a polishing pad while supplying a polishing liquid onto the polishing pad. A slurry containing abrasive grains is usually used for the polishing liquid. A polishing apparatus for performing CMP includes a polishing table configured to support a polishing pad having a polishing surface, and a polishing head configured to press the workpiece against the polishing pad.

[0003] The polishing apparatus polishes the workpiece as follows. The polishing liquid (typically the slurry) is supplied onto the polishing surface of the polishing pad while the polishing table and the polishing pad are rotating integrally. The polishing head presses a surface of the workpiece against the polishing surface of the polishing pad while rotating the workpiece. The workpiece is brought into sliding contact with the polishing pad in the presence of the polishing liquid. The surface of the workpiece is polished by a chemical action of the polishing liquid and a mechanical action of the abrasive grains contained in the polishing liquid and/or the polishing pad.

[0004] A polishing rate (also referred to as a removal rate) of the workpiece can change depending on various factors. A condition of polishing pad is one of the factors affecting the polishing rate. Specifically, the polishing liquid is retained on the polishing surface

of the polishing pad, and the workpiece is brought into sliding contact with the polishing surface. The polishing pad has a large number of minute protrusions on its polishing surface. These large number of protrusions contribute to mechanical polishing of the workpiece. Therefore, the condition of polishing pad can affect the polishing rate of the workpiece.

[0005] Therefore, in order to improve and stabilize the polishing rate of the workpiece, dressing of the polishing surface of the polishing pad is performed before polishing of the workpiece (hereinafter, dressing of the polishing surface of the polishing pad may be referred to as pad dressing). The pad dressing is performed using a dresser having a dressing surface made of abrasive grains, such as diamond particles. More specifically, the dressing surface of the dresser is pressed against the polishing surface of the polishing pad while the polishing pad and the dresser are rotated individually, so that the polishing surface is roughened (i.e., a large number of minute protrusions are formed on the polishing surface).

Citation List

Patent Literature

[0006] Patent document 1: Japanese laid-open patent publication No. 2010-76049

Summary of Invention

Technical Problem

[0007] The pad dressing is performed under a predetermined dressing condition. It is desirable that the polishing surface of the polishing pad has uniform asperity over its entirety. Therefore, the dressing condition is determined so that such a polishing surface can be achieved. However, conventionally, a user determines the dressing condition by trial and error, and there has been a case where an intended dressing result cannot be obtained.

[0008] Therefore, the present invention provides a technique capable of automatically determining the dressing condition capable of realizing a desired condition of polishing pad.

Solution to Problem

[0009] In an embodiment, there is provided a dressing-condition determining apparatus for determining a dressing condition for dressing a rotating polishing pad by pressing a dressing surface of a rotating dresser against the polishing pad, comprising: a memory storing an estimation model constructed by machine learning; and a processor configured to execute an arithmetic operation according to an algorithm of the estimation model, wherein the estimation model is configured to output the dressing condition for realizing target paths of a plurality of abrasive grains on the polishing pad when a target-path image indicating the target paths is inputted into the estimation model, the plurality of abrasive grains constituting the dressing surface.

[0010] In an embodiment, the dressing condition includes at least one of a rotational speed of the dresser, a rotational speed of the polishing pad, an oscillation speed of the dresser on the polishing pad, and a dressing time.

In an embodiment, the target-path image is a simulation image of the paths of the plurality of abrasive grains generated by executing a simulation of an operation of dressing the polishing pad by pressing the dressing surface of the rotating dresser against the rotating polishing pad.

In an embodiment, the estimation model is a trained model constructed by the machine learning using training data including a plurality of dressing conditions and a plurality of path images obtained by dressing simulations performed under the plurality of dressing conditions.

In an embodiment, the estimation model includes: an encoder configured to extract a feature of the target-path image; a decoder configured to restore the target-path image from the feature; and a regression analyzer configured to perform a regression analysis on the extracted feature to output the dressing condition.

In an embodiment, the target paths are such that paths of the abrasive grains are uniformly distributed over the polishing pad, and intersections of the paths of the abrasive grains are uniformly distributed over the polishing pad.

[0011] In an embodiment, there is provided a dressing-condition determining method of

determining a dressing condition for dressing a rotating polishing pad by pressing a dressing surface of a rotating dresser against the polishing pad, comprising: inputting a target-path image indicating target paths of a plurality of abrasive grains on the polishing pad into an estimation model constructed by machine learning, the plurality of abrasive grains constituting the dressing surface; and outputting the dressing condition for realizing the target paths from the estimation model.

[0012] In an embodiment, the dressing condition includes at least one of a rotational speed of the dresser, a rotational speed of the polishing pad, an oscillation speed of the dresser on the polishing pad, and a dressing time.

In an embodiment, the target-path image is a simulation image of the paths of the plurality of abrasive grains generated by executing a simulation of an operation of dressing the polishing pad by pressing the dressing surface of the rotating dresser against the rotating polishing pad.

In an embodiment, the estimation model is a trained model constructed by the machine learning using training data including a plurality of dressing conditions and a plurality of path images obtained by dressing simulations performed under the plurality of dressing conditions.

In an embodiment, the estimation model includes: an encoder configured to extract a feature of the target-path image; a decoder configured to restore the target-path image from the feature; and a regression analyzer configured to perform a regression analysis on the extracted feature to output the dressing condition.

In an embodiment, the target paths are such that paths of the abrasive grains are uniformly distributed over the polishing pad, and intersections of the paths of the abrasive grains are uniformly distributed over the polishing pad.

Advantageous Effects of Invention

[0013] The dressing-condition determining apparatus and the dressing-condition determining method described above can automatically determine the dressing condition capable of realizing a desired condition of polishing pad by using the estimation model.

Brief Description of Drawings

[0014]

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

[FIG. 2] FIG. 2 is a schematic diagram showing an example of paths of abrasive grains constituting a dressing surface on a polishing surface of a polishing pad.

[FIG. 3] FIG. 3 is a diagram showing an example of a target-path image.

[FIG. 4] FIG. 4 is a schematic diagram showing an embodiment of an estimation model.

[FIG. 5] FIG. 5 is a schematic diagram showing an example of training data including a plurality of dressing conditions and a plurality of corresponding path images.

[FIG. 6] FIG. 6 is a schematic diagram for explaining a training phase of constructing the estimation model by machine learning using the training data.

[FIG. 7] FIG. 7 is a schematic diagram for explaining a practical phase of determining a dressing condition for realizing paths of abrasive grains on a target-path image by using the estimation model constructed by the machine learning.

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Description of Embodiments

[0015] 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 polishing apparatus. The polishing apparatus is an apparatus configured to chemically mechanically polish a wafer W, which is an example of a workpiece for use in manufacturing semiconductor devices. As shown in FIG. 1, this polishing apparatus includes a polishing table 5 configured to support a polishing pad 2 having a polishing surface 2a, a polishing head 7 configured to press the wafer W against the polishing surface 2a, a polishing-liquid supply nozzle 8 configured to supply a polishing liquid (for example, a slurry containing abrasive grains) onto the polishing surface 2a, and an operation controller 30 configured to control an operation of the polishing apparatus.

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[0016] The polishing head 7 is configured to be able to hold the wafer W on its lower surface. The wafer W has a film to be polished. In the following embodiments, a wafer

is used as an example of the workpiece, but the workpiece is not limited to the wafer, and may be a circular substrate, a quadrilateral substrate, or a panel for use in manufacturing semiconductor devices.

[0017] The polishing apparatus further includes a support shaft 14, a polishing-head oscillating arm 16 coupled to an upper end of the support shaft 14, and a polishing-head shaft 18 rotatably supported by a distal end of the polishing-head oscillating arm 16. The polishing head 7 is fixed to a lower end of the polishing-head shaft 18. A polishing-head rotating mechanism (not shown) having an electric motor and the like is disposed in the polishing-head oscillating arm 16. This polishing-head rotating mechanism is coupled to the polishing-head shaft 18, and is configured to rotate the polishing-head shaft 18 and the polishing head 7 in a direction indicated by an arrow.

[0018] The polishing-head shaft 18 is coupled to a polishing-head elevating mechanism (including a ball screw mechanism and the like) which is not shown in the drawings. This polishing-head elevating mechanism is configured to vertically move the polishing-head shaft 18 relative to the polishing-head oscillating arm 16. By the vertical movement of the polishing-head shaft 18, the polishing head 7 can move vertically relative to the polishing-head oscillating arm 16 and the polishing table 5, as indicated by an arrow.

[0019] The polishing apparatus further includes a table-rotating motor 21 configured to rotate the polishing pad 2 and the polishing table 5 about their axes. The table-rotating motor 21 is disposed below the polishing table 5, and the polishing table 5 is coupled to the table-rotating motor 21 via a table shaft 5a. The polishing table 5 and the polishing pad 2 are configured to be rotated in a direction indicated by an arrow about the table shaft 5a by the table-rotating motor 21. The polishing pad 2 is attached to an upper surface of the polishing table 5. An exposed surface of the polishing pad 2 constitutes the polishing surface 2a for polishing the wafer W.

[0020] The polishing of the wafer W is performed as follows. The wafer W, with its surface to be polished facing downward, is held by the polishing head 7. While the polishing head 7 and the polishing table 5 are rotated independently, the polishing liquid

(for example, the slurry containing the abrasive grains) is supplied from the polishing-liquid supply nozzle 8, provided above the polishing table 5, onto the polishing surface 2a of the polishing pad 2. The polishing pad 2 is rotated together with the polishing table 5 about its central axis. The polishing head 7 is moved to a predetermined height by the polishing-
5 head elevating mechanism (not shown). Furthermore, the polishing head 7 presses the wafer W against the polishing surface 2a of the polishing pad 2 while the polishing head 7 is maintained at the predetermined height. The wafer W rotates together with the polishing head 7. The wafer W is brought into sliding contact with the polishing surface 2a of the polishing pad 2 in the presence of the polishing liquid on the polishing surface 2a.
10 The surface of the wafer W is polished by a combination of a chemical action of the polishing liquid and a mechanical action of the abrasive grains contained in the polishing liquid and/or the polishing pad 2.

[0021] The operation controller 30 is composed of at least one computer. The operation controller 30 includes a memory 30a in which a program is stored, and an arithmetic device
15 30b configured to execute an arithmetic operation according to an instruction included in the program. 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) or a solid state drive (SSD). Examples of the arithmetic device 30b include a CPU (Central Processing Unit) and a GPU (Graphics Processing Unit). However, a specific configuration of the
20 operation controller 30 is not limited to these examples.

[0022] The polishing apparatus includes a dressing mechanism 50 configured to dress the polishing surface 2a of the polishing pad 2. This dressing mechanism 50 includes a dresser 51 configured to be brought into sliding contact with the polishing surface 2a of the
polishing pad 2, a dresser shaft 52 to which the dresser 51 is coupled, and a dresser
25 oscillating arm 55 configured to rotatably support the dresser shaft 52. A lower surface of the dresser 51 constitutes a dressing surface 51a, and this dressing surface 51a is composed of abrasive grains (for example, diamond particles).

[0023] The dresser shaft 52 is coupled to a dresser pressing mechanism (for example,

including an air cylinder), which is not shown in the drawings, disposed in the dresser oscillating arm 55. This dresser pressing mechanism is configured to press the dressing surface 51a of the dresser 51 against the polishing surface 2a of the polishing pad 2 via the dresser shaft 52. Furthermore, the dresser shaft 52 is coupled to a dresser rotating
5 mechanism (for example, including an electric motor), which is not shown in the drawings, disposed in the dresser oscillating arm 55. This dresser rotating mechanism is configured to rotate the dresser 51 in a direction indicated by an arrow via the dresser shaft 52.

[0024] The dressing of the polishing surface 2a of the polishing pad 2 is performed as follows. While the polishing pad 2 is rotated by the table-rotating motor 21 together with
10 the polishing table 5, pure water is supplied onto the polishing surface 2a from a pure-water supply nozzle not shown. While the dresser 51 is rotated about the dresser shaft 52 by the dresser rotating mechanism (not shown), the dressing surface 51a of the dresser 51 is pressed against the polishing surface 2a by the dresser pressing mechanism (not shown). The dresser 51 is brought into sliding contact with the polishing surface 2a in the presence
15 of the pure water on the polishing surface 2a,. During the rotation of the dresser 51, the dresser oscillating arm 55 is rotated about a support shaft 58 to oscillate the dresser 51 in a radial direction of the polishing surface 2a. In this way, the polishing pad 2 is slightly scraped off by the dressing surface 51a of the dresser 51, so that the polishing surface 2a is dressed (regenerated).

20 [0025] Dressing of the polishing pad 2 is carried out before a new polishing pad 2 is used for polishing a wafer for the first time, or during polishing of a wafer, or after polishing of a wafer and before polishing of a next wafer.

[0026] The dressing of the polishing pad 2 is performed under a predetermined dressing condition. The dressing condition includes at least one of a rotational speed of the dresser
25 51, a rotational speed of the polishing pad 2 (and the polishing table 5), a dressing time, and an oscillation speed of the dresser 51 on the polishing surface 2a.

[0027] During the dressing of the polishing pad 2, the abrasive grains constituting the dressing surface 51a roughen the polishing surface 2a by scratching the polishing surface

2a while moving on the polishing surface 2a of the polishing pad 2. FIG. 2 is a schematic diagram showing an example of paths of the abrasive grains constituting the dressing surface 51a on the polishing surface 2a of the polishing pad 2. A symbol T shown in FIG. 2 represents a path of an abrasive grain on the polishing surface 2a. As shown in FIG. 2, the abrasive grains scratch the polishing surface 2a, so that a part of the polishing surface 2a is raised to form a protrusion 40. Similarly, at an intersection where a plurality of paths T of the abrasive grains intersect, a part of the polishing surface 2a is raised to form a protrusion 40.

[0028] At the intersection of the paths T, the plurality of paths intersect at an intersection angle greater than 0 degrees. When the intersection angle is 0 degrees, the protrusion 40 formed by a certain abrasive grain may be removed by another abrasive grain. Therefore, the intersection angle of the paths T of the abrasive grains is greater than 0 degrees, for example, in a range of 10 to 170 degrees.

[0029] A large number of protrusions 40 formed by the abrasive grains of the dresser 51 contribute to the mechanical polishing of the wafer. Therefore, the condition of polishing surface 2a of the polishing pad 2 can affect a polishing rate of the wafer. In order to improve and stabilize the polishing rate of the wafer, it is desirable that the paths of the abrasive grains are uniformly distributed over the polishing pad 2, and the intersections of the paths of the abrasive grains are uniformly distributed over the polishing pad 2. The paths of the abrasive grains in the polishing surface 2a can change depending on the dressing condition.

[0030] Therefore, in order to create a desired condition of the polishing surface 2a of the polishing pad 2, the polishing apparatus further includes a dressing-condition determining apparatus 60 configured to determine the dressing condition, as shown in FIG. 1. The dressing-condition determining apparatus 60 is coupled to the operation controller 30.

[0031] The dressing-condition determining apparatus 60 is composed of at least one computer. The dressing-condition determining apparatus 60 includes a memory 60a in which a program and an estimation model 62 are stored, and a processor 60b configured to

execute arithmetic operations according to an instruction included in the program and an algorithm of the estimation model 62. The memory 60a includes a main memory, such as a random access memory (RAM), and an auxiliary memory, such as a hard disk drive (HDD) or a solid state drive (SSD). Examples of the processor 60b include a CPU
5 (Central Processing Unit) and a GPU (Graphics Processing Unit). However, a specific configuration of the dressing-condition determining apparatus 60 is not limited to these examples.

[0032] In an embodiment, the operation controller 30 and the dressing-condition determining apparatus 60 may be integrally constructed. For example, the operation
10 controller 30 and the dressing-condition determining apparatus 60 may be configured from a single computer.

[0033] The estimation model 62 is configured to output the dressing condition for realizing target paths of the plurality of abrasive grains on the polishing pad 2 when a target-path image is inputted into the estimation model 62. The plurality of abrasive grains
15 constitute the dressing surface 51a. The target-path image is indicative of the target paths. The estimation model 62 is a trained model constructed by machine learning. An example of the estimation model 62 is a neural network.

[0034] The target-path image is a simulation image generated by executing a simulation of an operation of dressing the polishing pad 2 by pressing the dressing surface 51a of the
20 rotating dresser 51 against the rotating polishing pad 2. The simulation may be executed by the dressing-condition determining apparatus 60 or may be executed by another simulation apparatus.

[0035] FIG. 3 is a diagram showing an example of the target-path image. In this example, the target paths of the abrasive grains appearing in the target-path image are
25 uniformly distributed over the polishing pad 2, and the intersections of the paths of the abrasive grains are uniformly distributed over the polishing pad 2. In other words, during the dressing of the polishing surface 2a of the polishing pad 2, the plurality of abrasive grains constituting the dressing surface 51a of the dresser 51 move uniformly on the

polishing surface 2a to form paths of geometric patterns. The plurality of abrasive grains move on the polishing surface 2a with travelling distances of uniform distribution.

[0036] The target-path image is inputted into the dressing-condition determining apparatus 60. The dressing-condition determining apparatus 60 inputs the target-path
5 image into the estimation model 62, and causes the estimation model 62 to output the dressing condition for realizing the target paths, which are the paths of the abrasive grains appearing in the target-path image. The dressing condition includes at least one of a rotational speed of the dresser 51, a rotational speed of the polishing pad 2, an oscillation speed of the dresser 51 on the polishing pad 2, and a dressing time.

10 [0037] FIG. 4 is a schematic diagram showing an embodiment of the estimation model 62. The estimation model 62 has an encoder 65 configured to extract a feature of the target-path image, a decoder 67 configured to restore the target-path image from the feature, and a regression analyzer 69 configured to perform a regression analysis on the extracted feature and output the dressing condition. The encoder 65 has an input layer 65a into
15 which the target-path image is inputted. The decoder 67 has an output layer 67a configured to output an image substantially the same as the target-path image inputted into the encoder 65. The encoder 65 is configured to compress the feature of the inputted target-path image and extract the feature of the target-path image. The decoder 67 is configured to restore the target-path image from the feature extracted by the encoder 65.
20 Such a combination of the encoder 65 and the decoder 67 constitutes an autoencoder.

[0038] The regression analyzer 69 is configured to perform the regression analysis on the feature extracted (compressed) by the encoder 65, and output the dressing condition capable of realizing the target paths which are the paths of the abrasive grains appearing on the target-path image that has been inputted into the encoder 65. The dressing condition
25 outputted from the regression analyzer 69 includes at least one of a rotational speed of the dresser 51, a rotational speed of the polishing pad 2, an oscillation speed of the dresser 51 on the polishing pad 2, and a dressing time.

[0039] The estimation model 62 is a trained model constructed by the machine learning.

More specifically, the estimation model 62 is a trained model constructed by the machine learning using training data. The training data includes a plurality of dressing conditions and a plurality of path images obtained by dressing simulations performed under the plurality of dressing conditions. The dressing simulation is a simulation of an operation
5 of dressing the polishing pad 2 with the dressing surface 51a of the dresser 51.

[0040] Each path image included in the training data is an image showing paths of the abrasive grains constituting the dressing surface 51a in the dressing simulation. The plurality of dressing conditions included in the training data are objective variables (i.e., correct labels or ground-truth levels), and the plurality of path images corresponding to the
10 plurality of dressing conditions are explanatory variables. The dressing simulation may be performed by the dressing-condition determining apparatus 60, or may be performed by another simulation apparatus.

[0041] FIG. 5 is a schematic diagram showing an example of the training data including a plurality of dressing conditions and a plurality of corresponding path images. The
15 dressing simulation is performed under each dressing condition, so that a path image of the abrasive grains corresponding to each dressing condition is obtained. A plurality of dressing conditions A to F shown in FIG. 5 are different from each other, and as a result, a plurality of path images A to F obtained by the dressing simulation are also different from each other. The plurality of dressing conditions A to F included in the training data
20 correspond one-to-one to the plurality of path images A to F included in the training data.

[0042] The dressing-condition determining apparatus 60 constructs the estimation model 62 by performing the machine learning using the training data. An example of the machine learning is deep learning, and an example of the estimation model 62 is a neural network. However, specific details of the machine learning and the estimation model 62
25 are not particularly limited, as long as the intended purpose can be achieved.

[0043] FIG. 6 is a schematic diagram for explaining a training phase of constructing the estimation model 62 by the machine learning using the training data. When one of the plurality of path images included in the training data is inputted into the input layer 65a of

the encoder 65, the path image is outputted from the output layer 67a of the decoder 67, and the dressing condition is outputted from the regression analyzer 69. A parameter (weight, threshold, etc.) of each node (neuron) of the encoder 65, the decoder 67, and the regression analyzer 69 is adjusted by the machine learning so that the path image outputted from the decoder 67 matches the path image inputted into the encoder 65, and the dressing condition outputted from the regression analyzer 69 matches the dressing condition corresponding to the path image inputted into the encoder 65. When a path image (e.g., the target-path image) that is not included in the training data is inputted into the estimation model 62 constructed by the machine learning, the estimation model 62 can output the dressing condition for realizing the paths of the abrasive grains appearing in the inputted path image.

[0044] FIG. 7 is a schematic diagram for explaining a practical phase of determining the dressing condition for realizing the paths of the abrasive grains in the target-path image by using the estimation model 62 constructed by the machine learning. The target-path image generated in advance by the simulation is inputted into the input layer 65a of the encoder 65 of the estimation model 62. The regression analyzer 69 of the estimation model 62 outputs the dressing condition capable of realizing the paths (i.e., the target paths) of the abrasive grains appearing in the target-path image.

[0045] The dressing condition outputted from the estimation model 62 is transmitted to the operation controller 30 shown in FIG. 1. The operation controller 30 controls the operation of the polishing apparatus including the dressing mechanism 50 according to the dressing condition to instruct the dressing mechanism 50 to dress the polishing surface 2a of the polishing pad 2. The dressing operation according to the dressing condition determined by the dressing-condition determining apparatus 60 can form the paths of the abrasive grains shown in the target-path image shown in FIG. 7 on the polishing surface 2a of the polishing pad 2.

[0046] The dressing-condition determining apparatus 60 and the dressing-condition determining method described above can automatically determine the dressing condition

capable of realizing the desired condition of the polishing pad by using the estimation model 62.

[0047] The dressing of the polishing pad 2 is performed at several timings. For example, before a new polishing pad 2 is used for polishing, the new polishing pad 2 is dressed by the dresser 51. This dressing operation is referred to as a break-in dressing. In another example, after a certain wafer is polished and before the next wafer is polished, the polishing pad 2 is dressed by the dresser 51. In still another example, during the polishing of the wafer, the polishing pad 2 is dressed by the dresser 51.

[0048] 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.

15 **Industrial Applicability**

[0049] The present invention is applicable to a technique for determining a dressing condition for dressing a polishing pad used in polishing a workpiece, such as a wafer, a substrate, or a panel.

Reference Signs List

20 [0050]

W wafer

T paths of abrasive grains

2 polishing pad

2a polishing surface

25 5 polishing table

5a table shaft

7 polishing head

8 polishing-liquid supply nozzle

	14	support shaft
	16	polishing-head oscillating arm
	18	polishing-head shaft
	21	table-rotating motor
5	30	operation controller
	30a	memory
	30b	arithmetic device
	40	protrusion
	50	dressing mechanism
10	51	dresser
	51a	dressing surface
	52	dresser shaft
	55	dresser oscillating arm
	60	dressing-condition determining apparatus
15	60a	memory
	60b	processor
	62	estimation model
	65	encoder
	67	decoder
20	69	regression analyzer

CLAIMS

[Claim 1] A dressing-condition determining apparatus for determining a dressing condition for dressing a rotating polishing pad by pressing a dressing surface of a rotating dresser against the polishing pad, comprising:

- 5 a memory storing an estimation model constructed by machine learning; and
a processor configured to execute an arithmetic operation according to an algorithm of the estimation model,
wherein the estimation model is configured to output the dressing condition for realizing target paths of a plurality of abrasive grains on the polishing pad when a target-
10 path image indicating the target paths is inputted into the estimation model, the plurality of abrasive grains constituting the dressing surface.

[Claim 2] The dressing-condition determining apparatus according to claim 1, wherein the dressing condition includes at least one of a rotational speed of the dresser, a
15 rotational speed of the polishing pad, an oscillation speed of the dresser on the polishing pad, and a dressing time.

[Claim 3] The dressing-condition determining apparatus according to claim 1, wherein the target-path image is a simulation image of the paths of the plurality of abrasive
20 grains generated by executing a simulation of an operation of dressing the polishing pad by pressing the dressing surface of the rotating dresser against the rotating polishing pad.

[Claim 4] The dressing-condition determining apparatus according to claim 1, wherein the estimation model is a trained model constructed by the machine learning using
25 training data including a plurality of dressing conditions and a plurality of path images obtained by dressing simulations performed under the plurality of dressing conditions.

[Claim 5] The dressing-condition determining apparatus according to claim 1,

wherein the estimation model includes:

an encoder configured to extract a feature of the target-path image;

a decoder configured to restore the target-path image from the feature; and

5 a regression analyzer configured to perform a regression analysis on the extracted feature to output the dressing condition.

[Claim 6] The dressing-condition determining apparatus according to claim 1, wherein the target paths are such that paths of the abrasive grains are uniformly distributed over the polishing pad, and intersections of the paths of the abrasive grains are uniformly
10 distributed over the polishing pad.

[Claim 7] A dressing-condition determining method of determining a dressing condition for dressing a rotating polishing pad by pressing a dressing surface of a rotating dresser against the polishing pad, comprising:
15 inputting a target-path image indicating target paths of a plurality of abrasive grains on the polishing pad into an estimation model constructed by machine learning, the plurality of abrasive grains constituting the dressing surface; and
outputting the dressing condition for realizing the target paths from the estimation model.

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[Claim 8] The dressing-condition determining method according to claim 7, wherein the dressing condition includes at least one of a rotational speed of the dresser, a rotational speed of the polishing pad, an oscillation speed of the dresser on the polishing pad, and a dressing time.

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[Claim 9] The dressing-condition determining method according to claim 7, wherein the target-path image is a simulation image of the paths of the plurality of abrasive grains generated by executing a simulation of an operation of dressing the polishing pad by

pressing the dressing surface of the rotating dresser against the rotating polishing pad.

[Claim 10] The dressing-condition determining method according to claim 7,
wherein the estimation model is a trained model constructed by the machine learning using
5 training data including a plurality of dressing conditions and a plurality of path images
obtained by dressing simulations performed under the plurality of dressing conditions.

[Claim 11] The dressing-condition determining method according to claim 7,
wherein the estimation model includes:
10 an encoder configured to extract a feature of the target-path image;
 a decoder configured to restore the target-path image from the feature; and
 a regression analyzer configured to perform a regression analysis on the extracted
feature to output the dressing condition.

15 [Claim 12] The dressing-condition determining method according to claim 7,
wherein the target paths are such that paths of the abrasive grains are uniformly distributed
over the polishing pad, and intersections of the paths of the abrasive grains are uniformly
distributed over the polishing pad.