

Description

Title of Invention:

METHOD FOR ESTIMATING EASE OF FINE POWDER
OCCURRENCE IN POLYSILICON, ESTIMATION DEVICE,
5 METHOD FOR PRODUCING POLYSILICON, TRAINED MODEL
GENERATION DEVICE AND GENERATION METHOD

Technical Field

[0001]

10 The present invention relates to a method and a device
for estimating a likelihood of generation of fine powder of
polysilicon, a method for producing polysilicon, and a device
and a method for generating a trained model.

15 Background Art

[0002]

There can be a case in which fine powder of polysilicon is
generated due to, for example, vibration during transportation.
The fine powder not only makes polysilicon difficult to handle,
20 but may also cause contamination of the polysilicon.

[0003]

It is considered that one of the factors of the generation
of fine powder is surface unevenness of polysilicon, which may
be caused depending on a state of deposition of the polysilicon.

There have been proposed methods for classifying polysilicon on the basis of a surface state of the polysilicon (for example, Patent Literatures 1 to 3).

5 Citation List

[Patent Literature]

[0004]

[Patent Literature 1]

Published Japanese Translation of PCT International
10 Application, *Tokuhyo*, No. 2022-537014

[Patent Literature 2]

Published Japanese Translation of PCT International
Application, *Tokuhyo*, No. 2016-516666

[Patent Literature 3]

15 Published Japanese Translation of PCT International
Application, *Tokuhyo*, No. 2009-532319

Summary of Invention

Technical Problem

20 [0005]

However, the techniques disclosed in Patent Literatures 1 to 3 do not focus on fine powder generated from polysilicon. As such, the techniques cannot be said to be suitable methods for separating polysilicon that is likely to generate fine powder.

[0006]

It is an object of an aspect of the present invention to provide a method and the like that make it possible to estimate a likelihood of generation of fine powder of polysilicon.

5 Solution to Problem

[0007]

In order to attain the object, a method in accordance with an aspect of the present invention for estimating a likelihood of generation of fine powder of polysilicon includes: an estimation
10 step of estimating, with use of a first trained model and from second captured image data including an image of second polysilicon that is a target of estimation, a likelihood of generation of fine powder of the second polysilicon when vibration is applied to the second polysilicon, the first trained
15 model being generated with use of, as training data, (i) determination data indicating a determination of whether or not an amount in which fine powder of first polysilicon is generated due to vibration applied to the first polysilicon is not more than a predetermined first threshold, the vibration satisfying a
20 predetermined condition and (ii) first captured image data including an image of the first polysilicon.

[0008]

In order to attain the object, a method in accordance with an aspect of the present invention for producing polysilicon

includes: an estimation step of estimating, with use of a first trained model and from second captured image data including an image of second polysilicon that is a target of estimation, a likelihood of generation of fine powder of the second polysilicon
5 when vibration is applied to the second polysilicon, the first trained model being generated with use of, as training data, (i) determination data indicating a determination of whether or not an amount in which fine powder of first polysilicon is generated due to vibration applied to the first polysilicon is not more than
10 a predetermined first threshold, the vibration satisfying a predetermined condition and (ii) first captured image data including an image of the first polysilicon; and a first separation step of separating the second polysilicon on the basis of the likelihood of generation of fine powder estimated in
15 the estimation step.

[0009]

In order to attain the object, an estimation device in accordance with an aspect of the present invention for estimating a likelihood of generation of fine powder of
20 polysilicon includes: an estimation section that estimates, with use of a first trained model and from second captured image data including an image of second polysilicon that is a target of estimation, a likelihood of generation of fine powder of the second polysilicon when vibration is applied to the second

polysilicon, the first trained model being generated with use of, as training data, (i) determination data indicating a determination of whether or not an amount in which fine powder of first polysilicon is generated due to vibration applied to the first polysilicon is not more than a predetermined first threshold, the vibration satisfying a predetermined condition and (ii) first captured image data including an image of the first polysilicon.

[0010]

10 In order to attain the object, a generation device in accordance with an aspect of the present invention for generating a trained model includes: an acquisition section that acquires, as training data, (i) determination data indicating a determination of whether or not an amount in which fine powder of first polysilicon is generated due to vibration applied to the first polysilicon is not more than a predetermined first threshold, the vibration satisfying a predetermined condition and (ii) first captured image data including an image of the first polysilicon; and a generation section that generates a first trained model that outputs, from second captured image data that is inputted to the first trained model and that includes an image of second polysilicon that is a target of estimation, an estimation result indicating an estimation of a likelihood of

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generation of fine powder of the second polysilicon when vibration is applied to the second polysilicon.

[0011]

In order to attain the object, a method in accordance with
5 an aspect of the present invention for generating a trained
model includes: an acquisition step of acquiring, as training
data, (i) determination data indicating a determination of
whether or not an amount in which fine powder of first
polysilicon is generated due to vibration applied to the first
10 polysilicon is not more than a predetermined first threshold,
the vibration satisfying a predetermined condition and (ii) first
captured image data including an image of the first polysilicon;
and a generation step of generating a first trained model that
outputs, from second captured image data that is inputted to
15 the first trained model and that includes an image of second
polysilicon that is a target of estimation, an estimation result
indicating an estimation of a likelihood of generation of fine
powder of the second polysilicon when vibration is applied to
the second polysilicon.

20 Advantageous Effects of Invention

[0012]

An aspect of the present invention makes it possible to
provide a method and the like that make it possible to estimate
a likelihood of generation of fine powder of polysilicon.

Brief Description of Drawings

[0013]

Fig. 1 is a schematic view illustrating an overview of a
5 part of a method for producing polysilicon.

Fig. 2 is a block diagram illustrating functional configurations of a generation device, an estimation device, and a separation control device in accordance with an embodiment of the present invention.

10 Fig. 3 is a flowchart illustrating a method for producing polysilicon in accordance with an embodiment of the present invention.

Fig. 4 is a view illustrating an example in which polysilicon is classified according to a surface state thereof.

15 Fig. 5 is a view illustrating a distribution of sizes of crushed pieces of polysilicon packed into a PE bag.

Fig. 6 is a view illustrating a direction and an intensity of vibration applied to crushed pieces of polysilicon.

Fig. 7 is a view illustrating amounts, respectively of
20 before and after a test transportation, of fine powder in a PE bag in which crushed pieces of polysilicon are packed.

Fig. 8 is a schematic view illustrating an overview of a first acquisition step to an estimation step illustrated in Fig. 3.

Fig. 9 is a schematic view illustrating an overview of a third acquisition step to an area ratio calculation step of calculating an area ratio of an uneven region illustrated in Fig. 3.

5 Fig. 10 is a schematic view illustrating an overview of the third acquisition step to a recess count calculation step illustrated in Fig. 3.

Fig. 11 is a view illustrating an example setting of a threshold in separation based on a total area of polysilicon and
10 an area ratio of an uneven region of the polysilicon.

Fig. 12 is a view illustrating an example setting of a threshold in separation based on a total area recess count of polysilicon.

15 Description of Embodiments

[0014]

[Overview of the present invention]

An embodiment of the present invention relates to a method for producing polysilicon. Polysilicon can be produced
20 by, for example, deposition with use of a bell jar or the like and trichlorosilane which serves as a raw material. Rod-shaped polysilicon thus deposited may have a varying surface state depending on, for example, a position at which the deposition took place.

[0015]

Specifically, the polysilicon which has been deposited may have unevenness on a surface thereof, and a degree of the unevenness varies depending on a position on the surface of the polysilicon. The unevenness may also be referred to as popcorns or cones due to resembling popcorns in shape.

[0016]

A highly uneven-surfaced portion of the polysilicon is of inferior quality. For example, the highly uneven-surfaced portion of the polysilicon is often brittle and is at high risk of cracking during transport. Furthermore, in the highly uneven portion, friction between polysilicon particles or between the polysilicon and a packaging material can easily cause fine powder to be generated. The fine powder not only makes the polysilicon difficult to handle, but can also cause contamination of the polysilicon.

[0017]

The fine powder may be polysilicon fragments or powder smaller than a predetermined size. For example, in a case where a size of polysilicon to be obtained as a product is approximately more than 5 mm and not more than 120 mm, fine powder may be polysilicon that has a size of not more than 5 mm.

[0018]

Thus, the size of the fine powder may be determined as appropriate depending on the size of the polysilicon. The size of the polysilicon and the size of the fine powder each indicate a long diameter. The long diameter indicates the maximum
5 distance between two points on the polysilicon or the fine powder. Note that it may be difficult to accurately measure a size of fine powder that has a long diameter of not more than 5 mm. As such, for example, in a case where fine powder is defined as powder that has a size of not more than 5 mm,
10 powder that passes through a 5 mm sieve may be considered to be fine powder.

[0019]

The rod-shaped polysilicon may be divided into segments for storage or transportation, by a dividing process such as
15 crushing or cutting. A surface state of such a segment varies depending on a position at which the segment was located on the rod-shaped polysilicon before the division. As such, physical properties such as a likelihood of generation of fine powder also differ among the segments. In the present
20 specification, what is referred to simply as "polysilicon" is not particularly limited in shape, and may be, for example, in the state of a rod or a segment.

[0020]

Fig. 1 illustrates an example of a method for crushing polysilicon to which the method for producing polysilicon in accordance with an embodiment of the present invention can be applied. Rod-shaped polysilicon P includes, on part of a surface thereof, an uneven region P1 in which unevenness with a predetermined roughness or more is present. In order to obtain crushed pieces of polysilicon that are less likely to generate fine powder, it is preferable to remove, from a group of crushed pieces of polysilicon, a crushed piece that includes the uneven region P1. In Fig. 1, crushed pieces that include the uneven region P1 are indicated as "WITH CONE", crushed pieces that do not include the uneven region P1 are indicated as "WITHOUT CONE", and a group of crushed pieces that is a mixture of crushed pieces including the uneven region P1 and crushed pieces not including the uneven region P1 is indicated as "CONE MIXED".

[0021]

In order to remove the crushed pieces including the uneven region P1, the above crushing method includes a rough crushing step S1, a crushing step S2, and a chipping step S3.

[0022]

The rough crushing step S1 is a step for, in order to remove the uneven region P1, separating the polysilicon P into a portion including the uneven region P1 on a surface thereof

and a portion not including the uneven region P1 on a surface thereof. The crushing step S2 is a step of crushing each of the portion including the uneven region P1 on the surface thereof and the portion not including the uneven region P1 on the surface thereof obtained in the rough crushing step S1, to thereby obtain crushed pieces. In a case where the portion not including the uneven region P1 among the polysilicon P is further crushed, a group of crushed pieces not including the uneven region P1 is obtained.

10 [0023]

In a case where the portion including the uneven region P1 among the polysilicon P is crushed, a group of crushed pieces is obtained which is a mixture of a crushed piece including the uneven region P1 and a crushed piece not including the uneven region P1. The crushed piece including the uneven region P1 is subjected to the chipping step S3 in which the crushed piece including the uneven region P1 is further crushed so that only the uneven region P1 is chipped off (i.e., chipping is carried out), whereby the crushed piece including the uneven region P1 can be separated into a crushed piece that does not include the uneven region P1 and a crushed piece that is mostly made up of the uneven region P1.

20 [0024]

The separation of crushed pieces in the chipping step S3 can also be done by a human by visually inspecting surface states of the crushed pieces. However, it has not been clear up to which degrees of surface state among the various surface states shown in Fig. 4 contribute to generation of fine powder during vibration. There has also been a problem that it is difficult to standardize criteria for determination made by the visual inspection or the like.

[0025]

10 According to an embodiment of the present invention, it is possible to separate polysilicon on the basis of a criterion that pertains to a correlation between the uneven region P1 and a likelihood of generation of fine powder and that has been learned on the basis of likelihoods of generation of fine powder
15 under a given vibration condition.

[0026]

In order to provide such a crushing method, in a method for producing polysilicon exemplified in Embodiment 1 (described later) of the present invention, a likelihood of
20 generation of fine powder of polysilicon is estimated with use of a trained model generated with use of training data, the training data being images of polysilicon that is likely to generate fine powder. Then, polysilicon is successfully separated on the basis of a result of the estimation. With this configuration,

polysilicon that does not include an uneven region P1 on a surface thereof and is unlikely to generate fine powder can be selected with high accuracy.

[0027]

5 Further, in a method for producing polysilicon exemplified in Embodiment 2 (described later) of the present invention, an area ratio of an uneven region P1 on a surface of polysilicon is estimated with use of a trained model generated with use of training data, the training data being surface states
10 of polysilicon that is likely to generate fine powder. By separating polysilicon on the basis of the area ratio and the like, it is possible to select polysilicon that is suitable for being subjected to the chipping step S3. With this configuration, it is possible to efficiently remove the uneven region P1 to thereby
15 greatly improve an efficiency of production of polysilicon.

[0028]

 Note here that extremely high purity is required of a polysilicon product. For this reason, polysilicon is etched for purification in the final stage before becoming a product. In
20 order to maintain surface cleanliness, it is desirable to package the polysilicon after the etching so that the polysilicon does not come into contact with anything other than polysilicon.

[0029]

It is a labor-intensive task to conduct pre-crushing inspection of a surface state before etching in order to remove the uneven region P1. For this reason, all conventional surface condition inspection methods target polysilicon after etching, 5 and serve as a final product inspection intended to prevent inclusion of foreign matter as well as inspecting a surface state. [0030]

As such, there are many chances of contact with gloves and the like of an inspection worker during post-etching 10 inspection work, and there is a risk of compromising the surface cleanliness during the post-etching inspection step. [0031]

As an example, the following assumes that a weight proportion of polysilicon P before the rough crushing step S1 is 15 100%. In this case, after the rough crushing step S1, the crushing step S2, and the chipping step S3 are carried out, a weight proportion of crushed pieces each of which includes an uneven region P1 and is unsuitable for use as a product is, for example, approximately 25%, although the weight proportion 20 varies depending on conditions under which the polysilicon P has been deposited. If the crushed pieces including the uneven region P1 can be detected before the etching, post-etching inspection of a surface state is unnecessary, and the surface cleanliness is not impaired. This improves the surface

cleanliness of the polysilicon in comparison to conventional methods. Further, it is possible to reduce the burden in the work of inspecting a surface state of polysilicon.

[0032]

5 According to the method for producing polysilicon in accordance with an embodiment of the present invention, a likelihood of generation of fine powder can be estimated before etching of polysilicon, and separation of polysilicon can be carried out on the basis of a result of the estimation. This is
10 because shapes of unevenness on a surface of polysilicon do not change significantly before and after etching, and a likelihood of generation of fine powder of a polysilicon product after etching can therefore be estimated with high accuracy by inspection before the etching.

15 [0033]

As a result, polysilicon that is likely to generate fine powder can be excluded from the target of the etching. In order to obtain more valuable polysilicon for semiconductors, it is only necessary to etch only polysilicon that is less likely to
20 generate fine powder. This greatly improves the efficiency of polysilicon production compared to conventional methods. This effect also contributes, for example, to achieving goal 12 "Ensure sustainable consumption and production patterns" and

the like of the Sustainable Development Goals (SDGs) proposed by the United Nations.

[0034]

Embodiment 1

5 As illustrated in Fig. 3, a method for producing polysilicon in accordance with the present embodiment includes at least an estimation step S14 and a first separation step S15, and may further include a first acquisition step S11, a first generation step S12, and a second acquisition step S13. In the
10 estimation step S14, for example, estimation is performed with use of a first trained model obtained in the first generation step S12. First, a method for generating a trained model in accordance with the present embodiment for acquiring the first trained model will be described.

15 [0035]

<Generation of first trained model>

 The method for generating a trained model in accordance with the present embodiment may be carried out, for example, by a generation device 10 for generating a trained model
20 illustrated in Fig. 2. Hereinafter, the method for generating a trained model will be described using an example in which the method is carried out by the generation device 10.

[0036]

As illustrated in Fig. 2, the generation device 10 includes a first acquisition section (acquisition section) 11 and a first generation section (generation section) 12. The generation device 10 may be a control device capable of carrying out processes of the first acquisition section 11 and the first generation section 12, and may be, for example, a central processing unit (CPU). Alternatively, the generation device 10 may be a device that includes such a control device and further includes a storage device, a communication device, and the like.

10 [0037]

(First acquisition step and first training data)

As illustrated in Fig. 3, the first acquisition section 11 carries out the first acquisition step (acquisition step) S11 for acquiring first training data that is used for generating a first trained model. The first training data is data including determination data and first captured image data. Determination data indicates whether or not an amount of generation of fine powder of first polysilicon to which vibration satisfying a predetermined condition is applied is not more than a predetermined first threshold, the fine powder being generated due to the vibration. The first captured image data includes an image of the first polysilicon.

20 [0038]

The first polysilicon is polysilicon whose likelihood of generation of fine powder due to vibration is known. For example, it is preferable that, for the first polysilicon, there exist information indicating how much fine powder has been
5 generated by application of vibration satisfying a predetermined condition.

[0039]

The first polysilicon may be, for example, an end product of polysilicon whose amounts of fine powder generated before
10 and after transportation are known. Alternatively, the first polysilicon may be a polysilicon sample or the like to which vibration is applied under conditions similar to those in product transportation and whose respective amounts of fine powder generated before and after the application of the vibration are
15 known. Note that the vibration applied to the first polysilicon does not have to be of a condition similar to that in product transportation, and may be vibration of a condition different from that in product transportation, such as a condition in an accelerated test.

20 [0040]

The first threshold in the determination data may be, for example, an allowable value of an amount of fine powder generated in response to vibration satisfying a predetermined condition. In this case, in a case where the amount of fine

powder generated is not more than the first threshold, the first polysilicon can be said to be polysilicon that is less likely to generate fine powder. There are no particular limitations on the method for setting the first threshold, and a suitable value for
5 separating polysilicon that is less likely to generate fine powder may be set as appropriate.

[0041]

The determination of whether or not the amount of fine powder of the first polysilicon generated is not more than the
10 first threshold may be made for each piece of first polysilicon on the basis of a measured value of an actual amount of fine powder generated. The determination may also be made on the basis of a surface state of the first polysilicon. This is based on a finding revealed by the inventors of the present invention
15 through experiments that the more uneven the surface of polysilicon is, the more likely fine powder is generated.

[0042]

As illustrated in Fig. 4, the inventors of the present invention classified crushed pieces of polysilicon
20 into groups according to their surface state. Specifically, the crushed pieces of polysilicon were classified relative to each other into eight groups, in which a group having the smoothest surface was classified as level 1, and a group having the roughest surface was classified as level 8. Fig. 4 shows an

example of images of surfaces of crushed pieces of polysilicon of the respective groups, the images being captured at the same magnification. The inventors of the present invention found that crushed pieces of polysilicon classified as levels 5 to 8 each
5 generated a larger amount of fine powder in comparison to crushed pieces of polysilicon classified as levels 1 to 4. In other words, the inventors of the present invention found that if polysilicon has a surface state classified as level 4 or lower, an amount of fine powder generated is likely to be within an
10 acceptable range for the polysilicon to be used as a product.

[0043]

Specifically, 5 kg of crushed pieces of polysilicon (nuggets) were prepared such that a weight distribution (weight %, left vertical axis) and a cumulative weight
15 distribution (weight %, right vertical axis) of the crushed pieces of polysilicon relative to a size (long diameter, horizontal axis) were as shown in Fig. 5, and the 5 kg of the crushed pieces of polysilicon were packed into a polyethylene (PE) bag. The size of each nugget was obtained by measuring a long diameter (i.e.,
20 a length of the longest side) of the nugget with use of a caliper. The sizes of the nuggets were in a range of 10 mm to 110 mm, and a median value thereof was approximately 70 mm. The PE bag was packed in a cardboard box, and a transport test was carried out over a round trip distance of approximately 400 km

(approximately 200 km one way). These conditions are equivalent to the transport conditions for polysilicon products. The cardboard box was loaded into a rear of a loading space of a transport truck, and a vibration meter with a three-axis
5 acceleration sensor was placed on top of the cardboard box.

[0044]

Fig. 6 shows results of measuring an acceleration (G) in each direction over time using a vibration meter, with the X-axis representing a direction of travel of the transport truck,
10 the Y-axis representing a right-and-left direction relative to the direction of travel, and the Z-axis representing an up-and-down direction. The X-axis has a positive value when, for example, a transport truck stops while traveling. This is because acceleration occurs in the direction of travel. The X-axis has a
15 negative value when, for example, the transport truck starts moving. The Y-axis has a positive value when the transport truck goes around a curve leftward relative to the direction of travel. This is because acceleration occurs rightward. The Y-axis has a negative value when the transport truck goes around
20 a curve rightward. The Z-axis has a value of approximately -1 G when the transport truck stays still, due to the effect of gravity. The Z-axis has a value more negative than -1 G when the cardboard box bounces upwards, and has a value more positive than -1 G when the cardboard box is pushed from above.

[0045]

As shown in Fig. 6, the cardboard box containing the nuggets was found to have large vertical movements and tilt more in rightward and leftward directions rather than in forward and backward directions. It is considered that the generation of fine powder from the nuggets occurs when the nuggets are subjected to such vibrations during transport, so that the nuggets collide or rub against each other. In this case, it is considered that the greater the unevenness of the surfaces of the nuggets, the more likely it is that fine powder will be generated by the collisions or the rubbing.

[0046]

Further, if there are recesses such as holes or cracks on the surfaces of the nuggets, fine powder that cannot be removed by etching may remain in the recesses. The fine powder can also be the cause of generation of fine powder by being ejected from the recesses by vibration.

[0047]

Fig. 7 shows results of two tests conducted under conditions similar to those for product transportation. In test 1, a comparison was made between a condition in which nuggets with surface states classified as levels 1 to 4 were packed in a PE bag and a condition in which nuggets with surface states classified as levels 1 to 8 were packed in a PE bag. In test 1,

PE bags (N = 25) were randomly sampled for measurement of an amount of fine powder before transportation (before shipping), and 14 PE bags (N = 14) were randomly sampled for measurement of an amount of fine powder after the test.

5 [0048]

Test 2 was conducted under the same transport conditions as those of test 1, on a day different from the day on which test 1 was conducted. In test 2, a comparison was made between a condition in which nuggets with surface states
10 classified as levels 1 to 6 were packed in a PE bag and a condition in which nuggets with surface states classified as level 5 or 6 were packed in a PE bag. In test 2, 10 PE bags (N = 10) were randomly sampled for measurement of an amount of fine powder, both before transportation (before shipping) and
15 after the test.

[0049]

The nuggets in each PE bag were separated based on size. First, the nuggets in the PE bag were separated using a 5 mm sieve. Fine powder that passed through the 5 mm sieve was
20 further separated using a 1 mm sieve. This resulted in obtaining three groups: fine powder with sizes of not more than 1 mm, fine powder with sizes of 1 mm to 5 mm, and nuggets with sizes over 5 mm. A weight (g) of each of the groups of fine powder was measured.

[0050]

As indicated in Fig. 7, it was shown in test 1 that the group of levels 1 to 8 showed a greater increase in the amount of fine powder after the test, in comparison to the group of levels 1 to 4. This is considered to be because the group of levels 1 to 8 contained many nuggets with rough surface states, so that an amount of fine powder generated increased compared to the group of levels 1 to 4.

[0051]

10 In test 2, it was shown that the group of levels 5 and 6 showed a greater increase in the amount of fine powder after the test, in comparison to the group of levels 1 to 6. This is considered to be because a ratio of nuggets with rough surface states was greater in the group of levels 5 and 6 than in the group of levels 1 to 6, and therefore the group of levels 5 and 6 had an increased amount of fine powder generated compared to the group of levels 1 to 6.

[0052]

20 As described above, it has been experimentally shown that the rougher the surface state of polysilicon, the more likely it is that fine powder of the polysilicon will be generated by vibration. Based on this knowledge, whether or not the amount of fine powder of the first polysilicon generated by vibration is not more than a predetermined first threshold may be

determined in a pseudo manner on the basis of whether or not the surface state of the first polysilicon has not more than a predetermined roughness.

[0053]

5 It is only necessary that the first captured image data include at least one captured image of the first polysilicon. It is preferable that the first captured image data be a plurality of images of the first polysilicon captured from respective different directions. More specifically, it is preferable that the first
10 captured image data include an image of a first surface, which is one surface of the first polysilicon, and an image of a second surface, which is a surface including a reverse side of the first surface.

[0054]

15 With this configuration, the first captured image data includes respective images of the front and back surfaces of the first polysilicon, and is therefore data suitable as an index indicative of a correlation between a surface state of the first polysilicon and a likelihood of generation of fine powder of the
20 first polysilicon. As such, with the first captured image data, it is possible to generate a first trained model that makes it possible to estimate, with high accuracy, a likelihood of generation of fine powder of second polysilicon which is a target of estimation.

[0055]

The first captured image data preferably includes (i) a plurality of images of the first surface of the first polysilicon captured from a respective plurality of directions and (ii) a
5 plurality of images of the second surface of the first polysilicon captured from a respective plurality of directions. The images of the first polysilicon included in the first captured image data are each preferably one that has as few shadow portions as possible. For example, it is preferable that capturing of images
10 of the first polysilicon be performed in a state where light fits the first polysilicon from a plurality of directions, by employing a method such as providing a plurality of light sources or causing diffused reflection of light inside a dome.

[0056]

15 In a case where the first captured image data includes a plurality of images, the first captured image data may be a composite image formed by combining the plurality of images. In a case where the first captured image data is such a composite image, the first generation section 12 only needs to
20 process a relatively small number of images as the first training data. This allows reducing the processing load. Note that the first captured image data may be data in an archive format that includes a plurality of individual images individually.

[0057]

(First generation step)

Next, the first generation section 12 carries out the first generation step (generation step) S12 of generating a first trained model with use of the determination data and the first captured image data as training data (first training data), the determination data and the first captured image data having been acquired by the first acquisition section 11. The first trained model functions as an algorithm that outputs, from second captured image data which has been inputted and which includes an image of the second polysilicon that is a target of estimation, an estimation result indicating an estimation of a likelihood that fine powder of the second polysilicon will be generated when vibration is applied.

[0058]

15 The second polysilicon is polysilicon that is a target of estimation of a likelihood of generation of fine powder with use of the first trained model. The second polysilicon is preferably polysilicon whose likelihood of generation of fine powder is unknown, but is not limited to such polysilicon. The second polysilicon may be, for example, polysilicon whose likelihood of generation of fine powder has been estimated by some method.

[0059]

The second captured image data is data including an image of the second polysilicon. It is only necessary that the

second captured image data include at least one captured image of the second polysilicon. It is preferable that the second captured image data be a plurality of images of the second polysilicon captured from respective different directions. More specifically, it is preferable that the second captured image data include an image of a third surface, which is one surface of the second polysilicon, and an image of a fourth surface, which is a surface including a reverse side of the third surface.

[0060]

10 With this configuration, the second captured image data includes respective images of the front and back surfaces of the second polysilicon, and is therefore data suitable as an index indicative of a correlation between a surface state of the second polysilicon and a likelihood of generation of fine powder of the second polysilicon. As such, the second captured image data is suitable as input data for estimating, with high accuracy, a likelihood of generation of fine powder of the second polysilicon.

[0061]

20 The second captured image data preferably includes (i) a plurality of images of the third surface of the second polysilicon captured from a respective plurality of directions and (ii) a plurality of images of the fourth surface of the second polysilicon captured from a respective plurality of directions. The images of the second polysilicon included in the second

captured image data are each preferably one that has as few shadow portions as possible, as with the images of the first polysilicon included in the first captured image data. For example, it is preferable that capturing of images of the second polysilicon be performed in a state where light fits the second polysilicon from a plurality of directions, by employing a method such as providing a plurality of light sources or causing diffused reflection of light inside a dome.

[0062]

10 An image format of the second captured image data is preferably the same as an image format of the first captured image data. For example, in a case where the first captured image data is a composite image of a plurality of images, the second captured image data is also preferably a composite image of a plurality of images. In this case, it is preferable that the number of images included in the second captured image data be the same as the number of images included in the first captured image data. With this configuration, an estimation can be easily made from the second captured image data with use
15
20 of the first trained model.

[0063]

The first generation step S12 carried out by the first generation section 12 can be said to be a step of optimizing a machine learning algorithm by inputting the first training data

into the machine learning algorithm. The first trained model can be said to be a machine learning algorithm that has been optimized, by input of the first training data, for estimating a likelihood of generation of fine powder of the second polysilicon.

5 Such a machine learning algorithm is not particularly limited, but may be, for example, a neural network. The machine learning algorithm may be, for example, a convolutional neural network (CNN).

[0064]

10 <Estimation using first trained model>

A method for estimating a likelihood of generation of fine powder of polysilicon in accordance with the present embodiment is carried out with use of the first trained model. The estimation method may be carried out by an estimation
15 device 20 for estimating a likelihood of generation of fine powder of polysilicon illustrated in Fig. 2. Hereinafter, the method for estimating a likelihood of generation of fine powder of polysilicon will be described using an example in which the method is performed by the estimation device 20.

20 [0065]

As illustrated in Fig. 2, the estimation device 20 includes a second acquisition section 21 and an estimation section 22. The estimation device 20 may be a control device capable of carrying out processes of the second acquisition section 21 and

the estimation section 22, and may be, for example, a central processing unit (CPU). Alternatively, the estimation device 20 may be a device that includes such a control device and further includes a storage device, a communication device, and the like.

5 [0066]

As illustrated in Fig. 3, the second acquisition section 21 carries out the second acquisition step S13 of acquiring the second captured image data. The second captured image data has already been explained, and explanation thereof is omitted
10 here.

[0067]

Subsequently, the estimation section 22 carries out the estimation step S14 of estimating, with use of the first trained model and from the second captured image data acquired by the
15 second acquisition section 21, a likelihood that fine powder of the second polysilicon will be generated when vibration is applied. The first trained model used by the estimation section 22 may be stored in advance in the estimation device 20, or may be acquired by the second acquisition section 21 from the
20 generation device 10 at any time.

[0068]

An estimation result indicating an estimation of a likelihood of generation of fine powder of the second polysilicon may be, for example, an estimation result indicating an

estimation of whether or not an amount of fine powder generated when vibration satisfying a predetermined condition is applied to the second polysilicon is not more than the first threshold corresponding to the vibration of the predetermined
5 condition. The amount of fine powder generated from the second polysilicon is considered to be positively correlated with an intensity of the applied vibration. As such, the estimation result is useful as an index of a likelihood of generation of fine powder of the second polysilicon, regardless of an actual intensity of
10 the vibration.

[0069]

In other words, the first trained model is generated on the basis of vibrations of a specific condition and a first threshold for the amount of generation of fine powder which first
15 threshold corresponds to the condition. However, with use of the first trained model, the estimation section 22 can estimate with high accuracy a relative likelihood of generation of fine powder of the second polysilicon, regardless of the condition of the vibration applied to the second polysilicon.

20 [0070]

Fig. 8 shows an overview of the steps from the first acquisition step S11 to the estimation step S14. In the example shown in Fig. 8, the first captured image data is a composite image including a plurality of images of the first polysilicon.

The determination data is data indicating a determination result in which an amount of fine powder generated is determined to be not more than the first threshold in a case where a surface state of the first polysilicon is levels 1 to 4, and
5 an amount of fine powder generated is determined to be more than the first threshold in a case where the surface state is levels 5 to 8.

[0071]

The first generation section 12 generates a first trained
10 model from the first captured image data and determination data having such a correspondence. The estimation section 22 inputs a composite image including a plurality of images of the second polysilicon as the second captured image data into the first trained model, to thereby estimate a likelihood of
15 generation of fine powder of the second polysilicon. Specifically, the estimation section 22 may indicate, as an estimation result indicating an estimation of the likelihood of generation of fine powder of the second polysilicon, a result of determination of whether or not the surface state of the second polysilicon is at
20 level 4 or lower.

[0072]

<Separation of second polysilicon>

The first separation step S15 is a step of separating the second polysilicon on the basis of the likelihood of generation

of fine powder estimated in the estimation step S14. The first separation step S15 may be carried out by a separation control device 30 illustrated in Fig. 2. The first separation step S15 may be a step carried out on the crushed pieces of polysilicon
5 obtained in the crushing step S2 shown in Fig. 1.

[0073]

As illustrated in Fig. 2, the separation control device 30 includes a first separation section 31. The separation control device 30 may be a control device capable of carrying out a
10 process of the first separation section 31, and may be, for example, a central processing unit (CPU). Alternatively, the separation control device 30 may be a device that includes such a control device and further includes a storage device, a communication device, and the like.

15 [0074]

The first separation section 31 may, for example, carry out control for separating third polysilicon from other pieces of second polysilicon, the third polysilicon being second polysilicon whose likelihood of generation of fine powder has
20 been estimated to be more than a predetermined second threshold in the estimation step S14. The second threshold may, for example, be a value that serves as an index that indicates that the second polysilicon is unsuitable for use as a commercial product in a case where a likelihood of generation

of fine powder of the second polysilicon is more than the second threshold.

[0075]

For example, in a case where an estimation result
5 obtained in the estimation step S14 indicates that the surface state of the second polysilicon is not more than a predetermined roughness, the first separation section 31 may determine that a likelihood of generation of fine powder of the second polysilicon not more than the second threshold.

10 [0076]

For the control for separating the second polysilicon, the first separation section 31 may transmit a control signal to a physical mechanism for separating the second polysilicon. Such a physical mechanism may be included in the separation control
15 device 30, or may be included in a device (not illustrated) for separating second polysilicon which device is different from the separation control device 30.

[0077]

The method for producing polysilicon in accordance with
20 the present embodiment, which has the configuration exemplified above, makes it possible to estimate with high accuracy a likelihood of generation of fine powder of the second polysilicon. Further, by estimating in advance second polysilicon that is less likely to generate fine powder, etching

can be performed only on that second polysilicon. This makes it possible to significantly improve the efficiency of production of polysilicon.

[0078]

5 Note that the control blocks provided in the generation device 10, the estimation device 20, and the separation control device 30 shown in Fig. 2 may be realized by a single control device. Further, the control blocks provided in the generation device 10 and the estimation device 20 may be realized by a
10 single control device, or the control blocks provided in the estimation device 20 and the separation control device 30 may be realized by a single control device.

[0079]

Embodiment 2

15 The following description will discuss Embodiment 2 of the present invention. For the convenience of description, a member having the same function as the member already described in Embodiment 1 is assigned the same reference numeral, and the description of the member is omitted.

20 [0080]

A method for producing polysilicon in accordance with the present embodiment includes a method for efficiently carrying out the chipping step S3 on the third polysilicon whose likelihood of generation of fine powder in the method for

producing polysilicon in accordance with Embodiment 1 has been estimated to be high.

[0081]

As illustrated in Fig. 3, the method for producing polysilicon in accordance with the present embodiment includes, in addition to the steps of the method for producing polysilicon in accordance with Embodiment 1, a third acquisition step S16, a second generation step S17, an area ratio calculation step S18, a recess count calculation step S19, and a second separation step S20. The area ratio calculation step S18 and the recess count calculation step S19 each perform a calculation process using, for example, the second trained model generated by the second generation step S17. First, a method for generating the second trained model will be described.

[0082]

<Generation of second trained model>

(Second acquisition step and second training data)

The second trained model functions as an algorithm for estimating whether or not the third polysilicon is suitable to be subjected to the chipping step S3. The generation of the second trained model may be carried out by the generation device 10. As illustrated in Fig. 2, the generation device 10 may include a

second generation section 13 for generating the second trained model.

[0083]

As illustrated in Fig. 3, in the present embodiment, a first acquisition section 11 may carry out the third acquisition step S16 of acquiring second training data which is used to generate the second trained model. The second training data includes surface state data indicating a surface state of first polysilicon whose amount of fine powder generated is more than a first threshold. Such a surface state of the first polysilicon may be, for example, a surface state having unevenness or recesses as indicated as the levels 5 to 8 in Fig. 4.

[0084]

The surface state data may be, for example, data including information that identifies (annotates), as uneven regions, regions in which the surface unevenness corresponds to levels 5 to 8 in the first captured image data of first polysilicon whose amount of fine powder generated is more than a first threshold, as shown in Fig. 9. The annotation may be carried out by a user inputting results of visual identification, or may be carried out mechanically by image processing.

[0085]

Further, as shown in Fig. 10, the surface state data may include information identifying recesses such as holes or cracks

formed on the surface of the first polysilicon, in addition to the information identifying uneven regions. It is preferable that no shadow portions be included in the images included in the first captured image data. However, depending on the way the light
5 hits the first polysilicon or the surface state during the image capturing, it is difficult to completely eliminate shadow portions from the images included in the first captured image data. As such, it may be difficult to determine whether or not a dark portion in an image included in the first captured image
10 data is a recess or a shadow.

[0086]

As such, the surface state data may be data including information that identifies (annotates) recessed portions in the first captured image data of the first polysilicon whose amount
15 of fine powder generated is more than the first threshold. The annotation may be carried out by a user inputting results of visual identification, or may be carried out mechanically by image processing.

[0087]

20 Such surface state data is suitable as second training data for creating a second trained model capable of identifying a portion of the third polysilicon which portion has a surface state that may cause generation of fine powder, as shown in Figs. 9 and 10.

[0088]

Note that the surface state data may be acquired by the first acquisition section 11 at the same time as the acquisition of the determination data and the first captured image data in the first acquisition step S11. In this case, the third acquisition step S16 may be omitted.

[0089]

(Second generation step)

Subsequently, the second generation section 13 carries out the second generation step S17 of generating a second trained model with use of the surface state data, which has been acquired by the first acquisition section 11, as training data (second training data). Specifically, the second trained model functions as an algorithm for calculating an area ratio of at least a part of a surface of the third polysilicon relative to a total area of the surface of the third polysilicon, the at least the part of the surface of the third polysilicon being inferred to have a surface state similar to the surface state of the first polysilicon whose amount of fine powder generated is more than the first threshold. Calculation of the area ratio will be described later as part of the description of the area ratio calculation step S18.

[0090]

The second generation step S17 carried out by the second generation section 13 can be said to be a step of optimizing a machine learning algorithm by inputting the second training data into the machine learning algorithm. The second trained
5 model can be said to be a machine learning algorithm that has been optimized, by input of the second training data, for estimating a portion that can be a cause of generation of fine powder of the third polysilicon.

[0091]

10 Such a machine learning algorithm is not particularly limited, but may be, for example, a neural network or a convolutional neural network (CNN). The machine learning algorithm used to generate the second trained model may be the same as the machine learning algorithm used to generate the
15 first trained model, or may be different.

[0092]

<Estimation using second trained model>

The second trained model is used in an estimation process using second captured image data of the third
20 polysilicon as an input in each of the area ratio calculation step S18 and the recess count calculation step S19. The area ratio calculation step S18 and the recess count calculation step S19 may be carried out by the estimation device 20. As illustrated in Fig. 2, the estimation device 20 may include an area ratio

calculation section 23 that carries out the area ratio calculation step S18 and a recess count calculation section 24 that carries out the recess count calculation step S19.

[0093]

5 (Area ratio calculation step)

The area ratio calculation section 23 calculates, from the second captured image data of the third polysilicon, an area ratio of at least a part of a surface of the third polysilicon relative to a total area of the surface of the third polysilicon, 10 the at least the part of the surface of the third polysilicon being inferred to have a surface state similar to the surface state of the first polysilicon whose amount of fine powder generated is more than the first threshold.

[0094]

15 The second captured image data of the third polysilicon may be data acquired by the second acquisition section 21 in the second acquisition step S13. In this case, the area ratio calculation section 23 may select only the second captured image data of the third polysilicon whose likelihood of 20 generation of fine powder is estimated to be more than the predetermined second threshold from among the second captured image data of the second polysilicon for which there is an estimation result of an estimation made in the estimation step S14. Further, the second acquisition section 21 may

acquire the second captured image data of the third polysilicon again before the area ratio calculation step S18.

[0095]

The area ratio calculation section 23 calculates a total
5 area of projected portions of the third polysilicon on the basis
of, for example, the second captured image data of the third
polysilicon captured at a 1x magnification, preferably at a 1x
magnification to 3x magnification. The total area of the
projected portions of the third polysilicon can be calculated
10 from the images included in the second captured image data. In
so doing, the area ratio calculation section 23 may calculate an
approximate total area two-dimensionally from the images
included in the second captured image data, or may estimate a
three-dimensional shape of the third polysilicon to calculate a
15 more accurate total area.

[0096]

For example, the area ratio calculation section 23
calculates a sum of the areas of the projected portions of the
third polysilicon captured from a plurality of directions, with
20 use of an algebraic expression of the number of pixels in the
projected portions of the third polysilicon. Then, a value
obtained by dividing the obtained sum by the number of image
capturing directions may be used as an index of a total area on
the surface of the third polysilicon. Note, however, that the

method by which the area ratio calculation section 23 calculates the total area of the surface of the third polysilicon is not limited to this.

[0097]

5 Note that, in a case where the image included in the second captured image data does not include a portion of the surface of the third polysilicon, the area ratio calculation section 23 may consider the total area of the surface appearing in the image included in the second captured image data to be
10 the total area of the surface of the third polysilicon.

[0098]

Subsequently, the area ratio calculation section 23 inputs the second captured image data of the third polysilicon to the second trained model, and estimates a position of an
15 uneven region, which is a surface region having a surface state similar to the surface state of the first polysilicon whose amount of fine powder generated is more than the first threshold. The uneven region in the third polysilicon can be said to be a surface region of at least a part of the third
20 polysilicon in which part an amount of fine powder generated is estimated to be large.

[0099]

The area ratio calculation section 23 calculates an area of the uneven region of which the estimation has been made.

The area ratio calculation section 23 calculates an area of the uneven region with use of the same method as for calculating the total area. In a case where the area ratio calculation section 23 infers that there are a plurality of independent uneven regions in the third polysilicon, the area ratio calculation section 23 may calculate an area of each of the uneven regions and a total area of the uneven regions individually, or the area ratio calculation section 23 may calculate only the total area of all of the uneven regions.

10 [0100]

For example, the area ratio calculation section 23 may, as with the surface area, calculate an index of an area of the uneven regions by (i) expressing a sum of respective areas of the portions considered to be the uneven regions with use of an algebraic expression of the number of pixels in the portions considered to be the uneven regions and (ii) dividing the sum by the number of image capturing directions to obtain a value to be used as the index of the area of the uneven region. Note, however, that the method by which the area ratio calculation section 23 calculates the area of the uneven regions on the surface of the third polysilicon is not limited to this.

[0101]

The second trained model has been trained with use of, as the training data, the surface state data of the first

polysilicon whose amount of fine powder generated is more than the first threshold. As such, by using the second trained model, the area ratio calculation section 23 is able to accurately estimate which portions of the surface of the third polysilicon
5 are uneven regions.

[0102]

Then, the area ratio calculation section 23 calculates an area ratio of the uneven regions relative to the total area of the third polysilicon. The area ratio of the uneven regions is used
10 to separate the third polysilicon in the second separation step S20 described later.

[0103]

(Recess count calculation step)

The recess count calculation section 24 carries out the
15 recess count calculation step S19 of calculating a recess count from the second captured image data of the third polysilicon and with use of the second trained model, the recess count being the number of portions each of which is inferred to be a recess formed in the surface of the third polysilicon. Note that,
20 in the method for producing polysilicon in accordance with the present embodiment, the recess count calculation step S19 may be omitted.

[0104]

The second trained model may be generated with use of training data that is surface state data including information identifying recesses such as holes or cracks formed on the surface of the first polysilicon (for example, holes, cracks or the
5 like having a total area of not less than 1 mm² in an image captured at a 1x magnification). In this case, use of the second trained model allows the recess count calculation section 24 to distinguish between a recess and a shadow formed on the surface of the third polysilicon, and to thereby infer the recess
10 with high accuracy. As described above, recesses formed on the surface of the third polysilicon cause the generation of fine powder after etching. It is therefore considered that the more recesses there are, the more likely the third polysilicon is to generate fine powder.

15 [0105]

The recess count calculated by the recess count calculation section 24 may be used to separate the third polysilicon in the second separation step S20 described below.

[0106]

20 <Separation of third polysilicon>

The second separation step S20 is a step of separating the third polysilicon on the basis of the total area and the area ratio calculated in the area ratio calculation step S18. The second separation step S20 may be a step of separating the

third polysilicon on the basis of the recess count calculated in the recess count calculation step S19 as well as the total area and the area ratio. The separating by the second separation step S20 may be aimed at separating third polysilicon to be
5 subjected to the chipping step S3 shown in Fig. 1.

[0107]

The second separation step S20 may be carried out by a separation control device 30 shown in Fig. 2. As illustrated in Fig. 2, the separation control device 30 may include a second
10 separation section 32 that performs the second separation step S20.

[0108]

The third polysilicon to be subjected to the chipping step S3 preferably has a total area not less than a predetermined
15 third threshold. This is because when a portion including an uneven region is to be chipped off from the third polysilicon by crushing or the like, the work becomes difficult if the third polysilicon is too small. For this reason, it is preferable that the second separation section 32 use the total area of the third
20 polysilicon as a criterion for separation of the third polysilicon.

[0109]

The third threshold may be set as appropriate by the method used in the chipping step S3. For example, the third threshold may be set to a different value when the chipping step

S3 is performed manually using a hammer or the like and when the chipping step S3 is performed mechanically using a crushing device.

[0110]

5 Further, it is preferable that the area ratio of uneven regions in the third polysilicon to be subjected to the chipping step S3 is not more than a predetermined fourth threshold. In a case where the area ratio of the uneven regions is too high, most of the surface of the third polysilicon will be uneven
10 regions, the chipping step S3 can obtain almost no third polysilicon that does not contain uneven regions. From the viewpoint of production efficiency, it is preferable that the second separation section 32 use the area ratio of the uneven regions in the third polysilicon as the criterion for separating
15 the third polysilicon.

[0111]

The fourth threshold may be set as appropriate according to a targeted product size of the third polysilicon. The fourth threshold may also be adjusted as appropriate according to the
20 total area of the third polysilicon. In a case where the total area of the third polysilicon is sufficiently large, a predetermined amount or more of third polysilicon that does not include uneven regions can be obtained after the chipping step S3 even if the fourth threshold is set to a large value.

[0112]

Further, it is preferable that the third polysilicon to be subjected to the chipping step S3 have a recess count of not more than a predetermined fifth threshold. Further, it is
5 preferable that the third polysilicon to be subjected to the chipping step S3 have a recess count of not less than a predetermined sixth threshold. In other words, it is preferable that the third polysilicon to be subjected to the chipping step S3 have a recess count of not less than the sixth threshold and
10 not more than the fifth threshold.

[0113]

Third polysilicon that has a high recess count is likely to have a large amount of fine powder generated, regardless of the area ratio of uneven regions. This is because fine powder that
15 cannot be removed by etching may exist within the recesses. Further, in a case where the recess count is extremely low and an estimation result of an estimation made by the estimation step S14 on the third polysilicon is that the likelihood of generation of fine powder of the third polysilicon is more than
20 the second threshold, it can be considered that the estimation result is due to a false detection of a shadow or the like contained in the second captured image data. For these reasons, it is preferable that the second separation section 32 use the

recess count of the third polysilicon as the criterion for separating the third polysilicon.

[0114]

The fifth and sixth thresholds may each be set as
5 appropriate, for example, empirically. The fifth and sixth
thresholds may also each be adjusted as appropriate according
to the total area of the third polysilicon. For the same recess
count, the larger the total area of the third polysilicon, the
fewer the recess count per unit area. It is preferable that the
10 likelihood of generation of fine powder of the third polysilicon
be considered per unit area.

[0115]

Figs. 11 and 12 show a relationship between a result of
separating polysilicon by visual observation and a total area,
15 an area ratio, and a recess count calculated by the area ratio
calculation section 23 and the recess count calculation section
24. In this case, the result of separation indicated is a result of
separating crushed pieces of polysilicon that are the "CONE
MIXED" obtained in the crushing step S2 shown in Fig. 1 and
20 which contain third polysilicon. Graphs in Fig. 11 show a
correlation between a total area and an area ratio of uneven
regions for the respective separated groups. Graphs in Fig. 12
shows a correlation between a total area and a recess count for
the respective separated groups. The total area of polysilicon is

the number of pixels in portions where the polysilicon is projected, the number of pixels being calculated from the image included in the second captured image data and representing an index of the total area.

5 [0116]

In Fig. 11, a graph 111 shows a distribution of all of the crushed pieces. A graph 112 shows a distribution of a group determined to not require the chipping step S3, a graph 113 shows a distribution of a group determined to be suitable to be
10 subjected to the chipping step S3, and a graph 114 shows a distribution of a group determined to be unsuitable to be subjected to the chipping step S3 even though a portion in which fine powder is likely to be generated is included.

[0117]

15 In Fig. 12, a graph 121 shows a distribution of a group obtained by excluding, from all of the crushed pieces, third polysilicon that has a total area index of not more than 10. Graphs 122 to 124 are similar in that third polysilicon with a total area index of not more than 10 is excluded. The graph 122
20 shows a distribution of a group determined to not require the chipping step S3, the graph 123 shows a distribution of a group determined to be suitable to be subjected to the chipping step S3, and the graph 124 shows a distribution of a group determined to be unsuitable to be subjected to the chipping step

S3 even though a portion in which fine powder is likely to be generated is included.

[0118]

In Fig. 11, regions indicated as "threshold range" are each
5 a region in which the index of the total area is greater than 10
and the area ratio of the uneven regions is not more than 65%.
It is indicated that polysilicon classified in such a region has a
total area that is not too small and an area ratio of the uneven
regions that is not too high, and therefore is highly likely to be
10 suitable to be subjected to the chipping step S3. Such a
threshold range may be an example setting of the third
threshold and the fourth threshold.

[0119]

In Fig. 12, regions in each of which the index of the total
15 area is greater than 10 and is sandwiched between the
"threshold range (upper limit)" and the "threshold range (lower
limit)" are empirically set regions in which a crushed piece that
is less likely to generate fine powder is likely to be plotted. It is
indicated that polysilicon classified in such a region is neither
20 too low nor too high in recess count relative to the total area,
and is therefore highly likely to be suitable to be subjected to
the chipping step S3. Such a region may be an example setting
of the third threshold, the fifth threshold, and the sixth
threshold.

[0120]

The third threshold to the sixth threshold may each be set on the basis of the actual measurement results as described above, or may be set empirically or by other methods.

5 [0121]

The second separation section 32 may, for example, separate the third polysilicon on the basis of the total area and the area ratio as shown in Fig. 11. The second separation section 32 may also carry out separation of the third polysilicon
10 such that the third polysilicon classified on the basis of the total area and the area ratio is further classified on the basis of the total area and the recess count as shown in Fig. 12.

[0122]

The second separation section 32 may transmit a control
15 signal to a physical mechanism for separating the third polysilicon. Such a physical mechanism may be included in the separation control device 30, or may be included in a device (not illustrated) for separating third polysilicon which device is different from the separation control device 30.

20 [0123]

The method for producing polysilicon in accordance with the present embodiment, which has the configuration exemplified above, can efficiently separate third polysilicon suitable for the chipping step S3. This makes it possible to

reduce both the labor cost and production loss required to obtain polysilicon that is less likely to generate fine powder.

[0124]

As an example, a weight proportion of polysilicon before
5 the rough crushing step S1 is taken as 100%. At this time,
polysilicon that is subjected to the chipping step S3 accounts
for a relatively large proportion of, for example, approximately
15%, though depending on the conditions of deposition of
polysilicon. For this reason, reducing a loss rate of polysilicon
10 by the chipping step S3 is important for improving production
efficiency. Therefore, the method for manufacturing polysilicon
in accordance with the present embodiment, which can improve
the efficiency of the chipping step S3, contributes greatly to
improving the production efficiency.

15 [0125]

[Software implementation example]

The respective functions of the generation device 10, the
estimation device 20, and the separation control device 30
(hereinafter, referred to as "device") can be realized by a
20 program for causing a computer to function as the device, the
program causing the computer to function as each of control
blocks of the device.

[0126]

In this case, the device includes, as hardware for executing the program, a computer which includes at least one control device (e.g., processor) and at least one storage device (e.g., memory). By execution of the program with use of the
5 control device and the storage device, each function described in each of the above-described Embodiments is realized.

[0127]

The program can be stored in at least one computer-readable non-transitory storage medium. The storage medium
10 can be provided in the device, or the storage medium does not need to be provided in the device. In the latter case, the program can be supplied to the device via any wired or wireless transmission medium.

[0128]

15 Further, one or some or all of respective functions of the control blocks described above can be realized by a logic circuit. For example, an integrated circuit in which a logic circuit that functions as the each control block is formed is also encompassed in the scope of the present invention. In addition,
20 it is also possible to realize the function of the each control block by, for example, a quantum computer.

[0129]

[Supplementary note]

The present invention is not limited to the embodiments,
but can be altered by a skilled person in the art within the scope
of the claims. The present invention also encompasses, in its
technical scope, any embodiment derived by combining
5 technical means disclosed in differing embodiments.

Reference Signs List

[0130]

- 10: Generation device
- 10 11: First acquisition section (acquisition section)
- 12: First generation section (generation section)
- 20: Estimation device
- 22: Estimation section
- 23: Area ratio calculation section
- 15 24: recess count calculation section

Claims

[Claim 1]

A method for estimating a likelihood of generation of fine
5 powder of polysilicon, the method comprising: an estimation
step of estimating, with use of a first trained model and from
second captured image data including an image of second
polysilicon that is a target of estimation, a likelihood of
generation of fine powder of the second polysilicon when
10 vibration is applied to the second polysilicon, the first trained
model being generated with use of, as training data, (i)
determination data indicating a determination of whether or not
an amount in which fine powder of first polysilicon is generated
due to vibration applied to the first polysilicon is not more than
15 a predetermined first threshold, the vibration satisfying a
predetermined condition and (ii) first captured image data
including an image of the first polysilicon.

[Claim 2]

20 The method as set forth in claim 1, wherein: the first
captured image data includes a plurality of images of the first
polysilicon captured from respective different directions; and

the second captured image data includes a plurality of images of the second polysilicon captured from respective different directions.

5 [Claim 3]

The method as set forth in claim 1 or 2, wherein: the first captured image data includes an image of a first surface of the first polysilicon and an image of a second surface of the first polysilicon, the second surface including a reverse side of the
10 first surface; and

the second captured image data includes an image of a third surface of the second polysilicon and an image of a fourth surface of the second polysilicon, the fourth surface including a reverse side of the third surface.

15

[Claim 4]

A method for producing polysilicon, the method comprising: an estimation step of estimating, with use of a first trained model and from second captured image data including
20 an image of second polysilicon that is a target of estimation, a likelihood of generation of fine powder of the second polysilicon when vibration is applied to the second polysilicon, the first trained model being generated with use of, as training data, (i) determination data indicating a determination of whether or not

an amount in which fine powder of first polysilicon is generated due to vibration applied to the first polysilicon is not more than a predetermined first threshold, the vibration satisfying a predetermined condition and (ii) first captured image data
5 including an image of the first polysilicon; and

a first separation step of separating the second polysilicon on the basis of the likelihood of generation of fine powder estimated in the estimation step.

10 [Claim 5]

The method as set forth in claim 4, further comprising:
an area ratio calculation step of calculating, with use of a second trained model and with use of the second captured image data of third polysilicon which is the second polysilicon
15 whose likelihood of generation of fine powder is estimated by the estimation step to be more than a predetermined second threshold, an area ratio of at least a part of a surface of the third polysilicon relative to a total area of the surface of the third polysilicon, the at least the part of the surface of the third
20 polysilicon being inferred to have a surface state similar to a surface state of the first polysilicon whose amount of fine powder generated is more than the first threshold, the second trained model being generated with use of, as training data, the

surface state of the first polysilicon whose amount of fine powder generated is more than the first threshold; and

a second separation step of separating the third polysilicon on the basis of the total area and the area ratio.

5

[Claim 6]

The method as set forth in claim 5, further comprising: a recess count calculation step of calculating a recess count with use of the second trained model and from the second captured
10 image data of the third polysilicon, the recess count being the number of portions each of which is inferred to be a recess formed in the surface of the third polysilicon,

the second separation step separating the third polysilicon on the basis of the recess count as well as the total
15 area and the area ratio.

[Claim 7]

An estimation device for estimating a likelihood of generation of fine powder of polysilicon, the estimation device
20 comprising: an estimation section that estimates, with use of a first trained model and from second captured image data including an image of second polysilicon that is a target of estimation, a likelihood of generation of fine powder of the second polysilicon when vibration is applied to the second

polysilicon, the first trained model being generated with use of,
as training data, (i) determination data indicating a
determination of whether or not an amount in which fine powder
of first polysilicon is generated due to vibration applied to the
5 first polysilicon is not more than a predetermined first
threshold, the vibration satisfying a predetermined condition
and (ii) first captured image data including an image of the first
polysilicon.

10 [Claim 8]

A generation device for generating a trained model, the
generation device comprising: an acquisition section that
acquires, as training data, (i) determination data indicating a
determination of whether or not an amount in which fine powder
15 of first polysilicon is generated due to vibration applied to the
first polysilicon is not more than a predetermined first
threshold, the vibration satisfying a predetermined condition
and (ii) first captured image data including an image of the first
polysilicon; and

20 a generation section that generates a first trained model
that outputs, from second captured image data that is inputted
to the first trained model and that includes an image of second
polysilicon that is a target of estimation, an estimation result
indicating an estimation of a likelihood of generation of fine

powder of the second polysilicon when vibration is applied to the second polysilicon.

[Claim 9]

5 A method for generating a trained model, the method comprising: an acquisition step of acquiring, as training data, (i) determination data indicating a determination of whether or not an amount in which fine powder of first polysilicon is generated due to vibration applied to the first polysilicon is not
10 more than a predetermined first threshold, the vibration satisfying a predetermined condition and (ii) first captured image data including an image of the first polysilicon; and
 a generation step of generating a first trained model that outputs, from second captured image data that is inputted to
15 the first trained model and that includes an image of second polysilicon that is a target of estimation, an estimation result indicating an estimation of a likelihood of generation of fine powder of the second polysilicon when vibration is applied to the second polysilicon.