

METHOD OF EVALUATING GLASS PLATE BASED ON ITS ELECTROSTATIC  
PROPERTIES, METHOD OF PRODUCING GLASS PLATE USING THE SAME,  
AND DEVICE USED FOR THE EVALUATION

5    Background of the Invention

1. Field of the Invention

The present invention relates generally to a method of evaluating a glass plate based on its electrostatic properties, a method of producing a glass plate using the same, and a device used for the evaluation.

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2. Related Background Art

A glass plate is used as a substrate for a flat panel display (FPD) such as a liquid crystal display or a plasma display. The FPD production process includes a step of placing a glass plate onto a table of a transfer system or processing equipment and lifting it from the table. With contact between the table and the glass plate as well as removal from each other, the glass plate, which is an insulator, accumulates static electricity. An excessively large amount of charge in the glass plate tends to cause a failure (electrostatic breakdown) in, for example, an electronic circuit that is formed on the substrate. Therefore, there is a need for a glass plate with low electrostatic properties that tends not to accumulate static electricity through contact with and removal from the table. In order to develop a glass plate with low electrostatic properties or in order to check whether a produced glass plate satisfies the predetermined standard with respect to the electrostatic properties, it is necessary to evaluate the electrostatic properties of the glass plate accurately.

25       JP 2005-255478 A discloses an invention relating to a glass plate that tends not to be charged due to contact with and removal from the table. In paragraphs [0027] to [0037] therein, it is described that contact between the table and the glass plate and removal from each other were repeated five times, the five maximum amounts of charge obtained after respective removals were added up, and the electrostatic properties of the glass plate were then evaluated based on the result.

30       The present inventor noticed that the conventional type of evaluation method as described in JP 2005-255478 A might not evaluate the electrostatic properties of a glass plate suitably in some cases. Such a problem may be caused by surface potential (initial potential) that may have been present in the glass plate before the operation of contact with and removal from the table is carried out. Although, for example, an ionizer is known as a device for subjecting a glass plate to a static elimination process, even when the static elimination process is carried out carefully

with such a device, it is not easy to remove the initial potential of the glass plate completely.

### Summary of the Invention

5           The present invention provides a method of evaluating a glass plate based on surface potential of the glass plate that is measured while a removal cycle is repeated, with the removal cycle that is carried out repeatedly including a placement step of placing the glass plate onto a placing platform and a separation step of separating the glass plate from the placing platform, wherein the removal cycle is carried out  
10 repeatedly at least until an increase in the absolute value of the surface potential according to an increase in the number of times of the removal cycles continues, and i) the removal cycle further is carried out repeatedly until the surface potential of the glass plate reaches a saturated charge potential, and a glass plate in which the absolute value of the saturated charge potential is smaller than a reference value A is evaluated  
15 as a glass plate with lower electrostatic properties, or ii) a glass plate in which a value obtained by dividing the amount of an increase in the absolute value of the surface potential over a period during which an increase in the absolute value of the surface potential continues, by the number of times of the removal cycles that are carried out during the period is smaller than a reference value B is evaluated as a glass plate with  
20 lower electrostatic properties.

          In the present specification, the state where “an increase in the absolute value of the surface potential continues” denotes a state where the absolute value of the surface potential of the glass plate increases continuously over a predetermined number of times of the removal cycles, more specifically, a state where the  
25 relationship in which the absolute value of the surface potential at the n-th removal cycle is larger than that of the surface potential at the n-1-th removal cycle (where n is an integer) continues over at least 50 removal cycles, preferably over 100 removal cycles or more. Furthermore, in the present specification, the saturated charge potential of the glass plate denotes the surface potential of the glass plate that is  
30 substantially constant even when the number of times of the removal cycles is increased, more specifically, it denotes the average value of the surface potential in at least 50 removal cycles in the case where with respect to the average value mentioned above, the variation in the surface potential in the at least 50 removal cycles is in the range of the following formula:

35    $|V_{ave} - V_n| \leq 50$ ,  
where  $V_{ave}$  is the average value (V) of the surface potential in 50 removal cycles, and  $V_n$  is the surface potential (V) at the n-th cycle in the 50 removal cycles.

From another aspect, the present invention provides a method of producing a glass plate with lower electrostatic properties, which includes forming a plurality of glass plates from a molten glass raw material, and evaluating electrostatic properties of the plurality of glass plates by using the above-mentioned evaluation method.

5 From further another aspect, the present invention provides a device for evaluating electrostatic properties of a glass plate, wherein the device includes a placing platform for placing a glass plate thereon, a lifting part for placing the glass plate onto and separating it from the placing platform, a measurement part for measuring surface potential of the glass plate, and a control part for controlling  
10 placing and removing of the glass plate by the lifting part as well as measurement of the surface potential by the measurement part, while allowing the measurement part to measure the surface potential, the control part controls the lifting part so that a removal cycle including an operation of placing the glass plate onto and separating it from the placing platform is repeated at least until an increase in the absolute value of  
15 the surface potential according to an increase in the number of times of the removal cycles continues, the device further includes an operation part for calculating, based on the surface potential, data to be used for a comparison with reference data for evaluating electrostatic properties of the glass plate, i) while allowing the measurement part to measure the surface potential, the control part controls the lifting  
20 part so that the removal cycle further is repeated until the surface potential reaches a saturated charge potential, and the operation part calculates the absolute value of the saturated charge potential as the data, or ii) the operation part calculates, as the data, a value obtained by dividing the amount of an increase in the absolute value of the surface potential over a period during which an increase in the absolute value of the  
25 surface potential continues, by the number of times of the removal cycles that are carried out during the period.

In the present invention, the removal cycle including the step of placing the glass plate onto the placing platform and the step of separating it therefrom is carried out repeatedly at least until an increase in the absolute value of the surface potential  
30 of the glass plate according to an increase in the number of times of the removal cycles continues. With the removal cycle repeated to the above-mentioned degree, physical quantities can be measured that can be used for the evaluation of electrostatic properties and that do not depend on the initial potential, and therefore the electrostatic properties of the glass plate can be evaluated accurately as compared to  
35 conventional cases.

### Brief Description of Drawings

FIG. 1 is a conceptual diagram for describing the configuration of a device for evaluating a glass plate according to the present invention.

FIG. 2 is a cross-sectional view showing the configuration of a vicinity of a placing platform in the device shown in FIG. 1.

FIGS. 3A and 3B are drawings for describing vertical movements of the glass plate in the device shown in FIG. 1.

FIG. 4 is a graph showing the relationship between the number of removal cycles and the surface potential in Sample A.

FIG. 5 is a graph showing the relationship between the number of removal cycles and the surface potential in Sample B.

### Detailed Description of the Invention

FIG. 1 is a conceptual diagram for describing the configuration of the evaluation device according to the present invention. FIG. 2 is a cross-sectional view showing the configuration of the vicinity of a placing platform 10 in the evaluation device 100. FIGS. 3A and 3B are drawings for describing vertical movements of a glass plate 200 in the evaluation device 100. As shown in FIG. 1, the evaluation device 100 is provided with the placing platform 10 for placing the glass plate 200, a lifting part 11, a measurement part 12, a control part 13, an operation part 14, and a display part 15.

As shown in FIG. 2, the lifting part 11 has a vertically movable lifting shaft 16, a lifting plate 17 attached to the upper end of the lifting shaft 16, and a plurality of lifter pins 18 that are disposed on the upper surface of the lifting plate 17 in such a manner as to protrude (upward in FIG. 2) toward the glass plate 200. The glass plate 200 is lifted upward from the placing platform 10 by the lifting part 11 from the state where it is placed on the placing platform 10, and then moves down to be placed on the placing platform 10 again. The vertical movements of the lifting shaft 16 are controlled by the control part 13. The table part 19 of the placing platform 10 has through-holes 20 formed therein. When the lifting shaft 16 is moved so that the lifting plate 17 approaches the table part 19 of the placing platform 10, the upper ends of the lifter pins 18 move inside the through-holes 20 to protrude from the table part 19.

When a separation step in which the glass plate 200 is separated from the placing platform 10 is carried out, static electricity is generated in the glass plate 200 along with the removal of the glass plate 200 from the table part 19. When the removal cycle including the placement step of placing the glass plate 200 onto the

placing platform 10 and the separation step is carried out repeatedly, static electricity is accumulated in the glass plate 200.

The table part 19 of the placing platform 10 is formed of metal such as aluminum. The surface of the table part 19 that comes into contact with the glass plate 200 has been subjected to insulation processing such as alumite processing. The lifter pins 18 are formed of metal such as aluminum. The upper end parts thereof that should come into contact with the glass plate 200 are covered with an insulating material such as resin. The table part 19 of the placing platform 10 has a suction hole (not shown in the drawings) formed therein, and the table part 19 also serves as a suction plate for fixing the glass plate 200 to the placing platform 10 by suction through the suction hole.

As shown in FIG. 1, the measurement part 12 has a measurement probe 12' for measuring the surface potential of the glass plate 200. As shown in FIG. 2, the measurement probe 12' is disposed in a position that is distant from the surface 21 of the glass plate 200 by a predetermined distance (distance d). The measurement part 12 is fixed to the lifting plate 17 of the lifting part 11 through the arm 30. With this configuration, as shown in FIGS. 3A and 3B, the measurement probe 12' moves vertically with respect to the table part 19 of the placing platform 10, along with the vertical movements of the lifting plate 17 and therefore the distance d between the surface 21 of the glass plate 200 and the measurement probe 12' is kept constant even during the removal cycle. The measured value of the surface potential of the glass plate 200 that is measured through the measurement probe 12' may vary depending on the distance d. In the evaluation device 100 of the present invention, however, since the distance d is kept constant as described above, inaccurate measurement due to such variations can be avoided.

While allowing the measurement part 12 to measure the surface potential of the glass plate 200, the control part 13 controls the movement of the lifting part 11 so that the removal cycle of the glass plate 200 is repeated at least until an increase in the absolute value of the surface potential according to an increase in the number of times of the removal cycles continues. The control part 13 controls the movement of the measurement part 12 so that the surface potential of the glass plate 200 is measured after the glass plate 200 is separated from the placing platform 10, more specifically, after the glass plate 200 is separated from the placing platform 10 but before it is placed onto the placing platform 10 at the subsequent removal cycle. It is preferable that the measurement of the surface potential by the measurement part 12 (measurement step) be controlled so as to be carried out at least once per removal cycle, but it may be controlled so as to be carried out once per predetermined number

of times of the removal cycles. The control part 13 also can control the movement of the lifting part 11 so that the removal cycle is repeated until the surface potential of the glass plate 200 reaches a saturated charge potential.

5 The surface potential of the glass plate 200 measured by the measurement part 12 is input to the operation part 14 through the control part 13. The operation part 14 calculates at least one of i) the absolute value of the saturated charge potential of the glass plate 200 and ii) a value (the rate of change in the absolute value of the surface potential) obtained by dividing the amount of an increase in the absolute value of the surface potential over a period during which an increase in the absolute value  
10 of the surface potential continues, by the number of times of the removal cycles that are carried out during the period, which are to be used for the comparison with reference data for evaluating the electrostatic properties of the glass plate based on the surface potential of the glass plate obtained after the removal cycles are carried out repeatedly. The absolute value of the saturated charge potential and the rate of  
15 change in the absolute value of the surface potential are physical quantities independent of initial potential. The rate of change in the absolute value of the surface potential is calculated based on the absolute values of the surface potentials in two removal cycles carried out at an interval of at least 50 times. When the reference is absolute values of the surface potentials in two removal cycles that are  
20 carried out at such a degree of interval, it is possible to disregard most influences of noise that may be included in the measured value of the surface potential.

The absolute value of the saturated charge potential and the rate of change in the absolute value of the surface potential that have been calculated by the operation part 14 are input to the display part 15 through the control part 13. The user of the  
25 evaluation device 100 can evaluate the electrostatic properties of the glass plate 200 by comparing the absolute value of the saturated charge potential and the rate of change in the absolute value of the surface potential displayed in the display part 15 with the values of corresponding reference data. More specifically, the electrostatic properties are evaluated to be satisfactory when the absolute value of the saturated  
30 charge potential and the rate of change in the absolute value of the surface potential are lower than the values of corresponding reference data. A reference value A, the reference data corresponding to the absolute value of the saturated charge potential, may be set according to the intended use of the glass plate. For instance, when the glass plate is used as a substrate for an FPD, it can be set to 2500 V. A reference  
35 value B, the reference data corresponding to the rate of change in the absolute value of the surface potential, may be set according to the intended use of the glass plate and the conditions for carrying out the removal cycle. For instance, when the glass

plate is used as a substrate for an FPD and the removal cycle is carried out using the evaluation device 100 as indicated in the example described later, it can be set to 8 V.

An embodiment also is possible in which the evaluation device according to the present invention further includes an evaluation part for evaluating electrostatic properties of the glass plate 200 by comparing the absolute value of the saturated charge potential and the rate of change in the absolute value of the surface potential with corresponding reference data, and the absolute value of the saturated charge potential and the rate of change in the absolute value of the surface potential are input to the evaluation part from the operation part 14 through the control part 13, signals of the evaluation of the electrostatic properties are input to the display part 15 through the control part 13, and the evaluation result is displayed on the screen of the display part 15. When the evaluation device is provided with the evaluation part, it is desirable that the user can select at least one of the reference value A and the reference value B as the reference data to be used for evaluating the electrostatic properties.

The method of evaluating a glass plate according to the present invention is described with an example in which it is carried out using the evaluation device 100. First, a glass plate to be evaluated is placed onto the placing platform 10 and is fixed to the table part 19 by suction through the suction hole. Preferably, the glass plate 200 is subjected to a static elimination process by using a known ionizer immediately after being placed onto the placing platform 10. In the case where the static elimination process is carried out, it is carried out only when the glass plate 200 is placed onto the placing platform 10 for the first time.

Next, with the suction fixation being suspended, the lifting part 11 is driven to lift the glass plate 200 upward from the placing platform 10 while allowing the upper ends of the lifter pins 18 to support the glass plate 200. Thereafter, the lifting part 11 is moved downward to place the glass plate 200 onto the placing platform 10 again, and the glass plate 200 is fixed to the placing platform 10 by suction through the suction hole. The removal cycle consisting of a step of placing the glass plate 200 onto the placing platform 10 and a step of separating it therefrom is repeated at least until an increase in the absolute value of the surface potential according to an increase in the number of times of the removal cycles continues, and in some cases, until the surface potential of the glass plate 200 reaches a saturated charge potential, with the measurement step being carried out. The absolute value of the saturated charge potential and the rate of change in the absolute value of the surface potential are then calculated by the measurement part 14 based on the surface potential of the glass plate 200 obtained at each measurement step.

When the glass plate 200 is in the state of having an initial potential, the absolute values of the surface potentials measured from the glass plate 200 in early stages of the removal cycles do not increase steady. As a result, when the surface potentials obtained in the early stages of the removal cycles are employed as indices, the electrostatic properties of the glass plate may not be evaluated suitably. However, repetition of the removal cycle to such a degree as described above makes it possible to specify the absolute value of the saturated charge potential and the rate of change in the absolute value of the surface potential that are physical quantities independent of the initial potential. The absolute value of the saturated charge potential obtained from the glass plate 200 is a value inherent to the glass plate 200 that depends on the composition and the surface roughness (Ra) of the glass plate 200, and it does not vary depending on the initial potential. The rate of change in the absolute value of the surface potential obtained from the glass plate 200 is a value determined by a combination of the glass plate 200 and the evaluation device 100, more specifically, a combination of, for example, the composition and surface roughness of the glass plate 200 and the surface roughness (Ra) and constituent material of the table part 19 of the placing platform 10 as well as the removal speed in the removal cycle. The rate of change also does not vary depending on the initial potential. Therefore, when the absolute value of the saturated charge potential and the rate of change in the absolute value of the surface potential are employed as indices, the electrostatic properties of the glass plate 200 can be evaluated suitably regardless of the presence or absence of the initial potential. The electrostatic properties of the glass plate 200 are evaluated by comparing the absolute value of the saturated charge potential and the rate of change in the absolute value of the surface potential with corresponding reference data.

In the process of producing the glass plate, surface potentials may be generated at various steps. For example, at a step where a molten glass raw material is formed into a plate shape and it is then carried by, for example, a roller conveyor, surface potential may be generated by friction between the roller and the glass plate surface due to contact between the glass plate and the roller and their removal from each other. Furthermore, for example, friction between air flow and the glass plate surface at a step of washing and drying the glass plate may generate surface potential.

The glass plate to be evaluated may be prepared uniquely through formation of a molten glass raw material or may be prepared by obtaining a commercial product.

In the above, the embodiment was described in which the glass plate is evaluated using the evaluation device according to the present invention. However,

the evaluation method according to the present invention can be an embodiment in which using, for example, a device that is not provided with the operation part 14, instead of the calculation of the absolute value of the saturated charge potential and the rate of change in the absolute value of the surface potential by the operation part 14, measured surface potential is output outside the device as numerical data and the user of the device calculates the absolute value of the saturated charge potential and the rate of change in the absolute value of the surface potential based on the numerical data.

According to the present invention, it also is possible to produce glass plates with a step of forming a plurality of glass plates from a molten glass raw material and a step of evaluating electrostatic properties of the plurality of glass plates by the above-mentioned evaluation method. This makes it possible to check whether the formed glass plates satisfy the predetermined standard with respect to the electrostatic properties and to select those satisfying the standard from the plurality of formed glass plates. Thus, glass plates with lower electrostatic properties can be provided further reliably.

Hereinafter, the present invention is described further in detail using examples.

Two types of glass plates (with a size of 680 mm × 880 mm and a thickness of 0.7 mm) whose surface roughnesses (Ra) were 0.2 nm and 0.5 nm were prepared, each of which had the following composition in terms of % by mass: SiO<sub>2</sub>: 60.9, B<sub>2</sub>O<sub>3</sub>: 11.6, Al<sub>2</sub>O<sub>3</sub>: 16.9, MgO: 1.7, CaO: 5.1, SrO: 2.6, BaO: 0.7, K<sub>2</sub>O: 0.25, Fe<sub>2</sub>O<sub>3</sub>: 0.15, and SnO<sub>2</sub>: 0.13. In the following description, among these glass plates, one with a surface roughness of 0.2 nm is referred to as Sample A, while one with a surface roughness of 0.5 nm is referred to as Sample B. It has been confirmed that Sample B has lower electrostatic properties as compared to Sample A.

Sample A was obtained as follows. That is, using a continuous melting apparatus provided with a firebrick melting tank and a platinum adjustment tank, a raw material batch was melted at 1580°C and was fined at 1650°C. After this was then formed into a thin plate shape by the down draw method while being stirred at 1500°C, it was cut into a predetermined size and the surface thereof was washed. Thus, Sample A was obtained. Sample B was obtained in the same manner as in the case of Sample A except that the surface of the glass plate was washed after a step of roughening the surface was carried out by immersing the glass plate in a glass etching solution containing hydrofluoric acid in the range of 120 seconds or shorter. The surface roughness of the glass plate and the surface roughness (Ra) of the table part of the placing platform described later were measured using an atomic force microscope.

The evaluation device 100 according to the present invention was installed in a clean room with a cleanliness class 1000, and the electrostatic properties of Sample A and Sample B were examined as described above. The table part 19 of the placing platform 10 had a surface roughness (Ra) of 1.6 mm. With respect to the atmosphere inside the clean room, the temperature and relative humidity were controlled to 20°C and 50%, respectively. The measurement probe used herein was 542-1 manufactured by TREAK. The distance  $d$  between the measurement probe and the glass plate was set at 25 mm. The distance for which the glass plate is lifted from the placing platform was set at 50 mm. The static elimination process was carried out using a known ionizer (SJ-H060, manufactured by Keyence Corporation) until the absolute value of the surface potential of the glass plate stopped decreasing even when the static elimination process was continued further. The removal cycle was carried out for the following fixed times: three seconds for placing the glass plate present in a position lifted 50 mm from the placing platform onto the placing platform by moving the lifter pins downward, three seconds for fixing the glass plate to the placing platform by suction, two seconds for stopping the suction and aligning the glass plate, seven seconds for lifting the glass plate to a position 50 mm distant from the placing platform by moving the lifter pins upward, and two seconds for aligning the glass plate after an upward movement. The phrase "aligning the glass plate" denotes an operation of adjusting the positional misalignment of the glass plate that has been caused by the operations of moving the lifter pins upward and downward. The surface potential of the glass plate was measured every 2.95 seconds, and among the data obtained during the period after removal of the glass plate from the placing platform but before placement thereof onto the placing platform in the subsequent removal cycle, one that had varied from 0 V most was extracted as the surface potential in each removal cycle.

FIGS. 4 and 5 show graphs that indicate variations in surface potential accompanying repetition of the removal cycle in Sample A and Sample B. As shown in FIGS. 4 and 5, in each sample, the absolute value of the surface potential did not increase steady due to the initial potential in the early stage of the repetition of the removal cycle (for example, to such a degree that the removal cycle was repeated 5 to 10 times). However, in both samples, when the removal cycle was repeated further, the absolute value of the surface potential increased substantially linearly from approximately the time when it was repeated more than 25 times.

The absolute value of the saturated charge potential of Sample A was 7134 V and that of Sample B was 2322 V. The absolute values of the saturated charge potentials of Sample A and Sample B each were calculated as the average value of the

absolute values of the surface potentials in the removal cycles carried out over the predetermined period immediately after the time when the increase in the absolute value of the surface potential of the glass plate stopped continuing, more specifically, as the average value of the absolute values of the surface potentials in the 377<sup>th</sup> to 428<sup>th</sup> removal cycles in the case of Sample A and in the 351<sup>st</sup> to 403<sup>rd</sup> removal cycles in the case of Sample B. Furthermore, the variations in surface potential in the removal cycles during those periods were in the range between  $-50\text{ V}$  and  $50\text{ V}$ . The surface potentials in the 119<sup>th</sup> and 237<sup>th</sup> removal cycles were  $-2540\text{ V}$  and  $-5005\text{ V}$  in the case of Sample A and  $-855\text{ V}$  and  $-1565\text{ V}$  in the case of Sample B. Based on this data, the rates of change in the absolute values of the surface potentials were calculated and were  $20.9\text{ V}$  in the case of Sample A and  $6.0\text{ V}$  in the case of Sample B.

As described above, Sample B, which is a glass plate that tends not to be charged, had a rate of change in the absolute value of the surface potential in the range of lower than  $8\text{ V}$  and an absolute value of the saturated charge potential in the range of lower than  $2500\text{ V}$ .

## CLAIMS

1. A method of evaluating a glass plate based on surface potential of the glass plate that is measured while a removal cycle is repeated, the removal cycle that is  
5 carried out repeatedly comprising a placement step of placing the glass plate onto a placing platform and a separation step of separating the glass plate from the placing platform,  
wherein the removal cycle is carried out repeatedly at least until an increase in the absolute value of the surface potential according to an increase in the number of  
10 times of the removal cycles continues, and  
i) the removal cycle further is carried out repeatedly until the surface potential of the glass plate reaches a saturated charge potential, and a glass plate in which the absolute value of the saturated charge potential is smaller than a reference value A is evaluated as a glass plate with lower electrostatic properties, or  
15 ii) a glass plate in which a value obtained by dividing the amount of an increase in the absolute value of the surface potential over a period during which an increase in the absolute value of the surface potential continues, by the number of times of the removal cycles that are carried out during the period is smaller than a reference value B is evaluated as a glass plate with lower electrostatic properties.  
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2. A method of producing a glass plate, comprising forming a plurality of glass plates from a molten glass raw material, and evaluating electrostatic properties of the plurality of glass plates by an evaluation method according to claim 1.
- 25 3. A device for evaluating an electrostatic property of a glass plate,  
wherein the device comprises a placing platform for placing a glass plate thereon, a lifting part for placing the glass plate onto and separating it from the placing platform, a measurement part for measuring surface potential of the glass plate, and a control part for controlling placing and removing of the glass plate by the  
30 lifting part as well as measurement of the surface potential by the measurement part,  
while allowing the measurement part to measure the surface potential, the control part controls the lifting part so that a removal cycle including an operation of placing the glass plate onto and separating it from the placing platform is repeated at least until an increase in the absolute value of the surface potential according to an  
35 increase in the number of times of the removal cycles continues,  
the device further comprises an operation part for calculating, based on the surface potential, data to be used for a comparison with reference data for evaluating

an electrostatic property of the glass plate, and

- i) while allowing the measurement part to measure the surface potential, the control part controls the lifting part so that the removal cycle further is repeated until the surface potential reaches a saturated charge potential, and the operation part
- 5 calculates the absolute value of the saturated charge potential as the data, or
- ii) the operation part calculates, as the data, a value obtained by dividing the amount of an increase in the absolute value of the surface potential over a period during which an increase in the absolute value of the surface potential continues, by the number of times of the removal cycles that are carried out during the period.