

WAFER, METHOD AND APPARATUS FOR IMPROVING ROUGHNESS OF THE WAFER, DEVICE, AND MEDIUM

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims a priority of the Chinese patent application No. 202411114022.0 filed on August 14, 2024, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure relates to the field of semiconductor manufacturing technology, in particular to a wafer, a method and an apparatus for improving roughness of the wafer, a device, and a medium.

BACKGROUND

[0003] During the manufacture of a wafer, after a single crystal silicon ingot is fabricated using a Czochralski method, the single crystal silicon ingot is sequentially subjected to such machining processes as wire sawing, lapping, etching, grinding, Chemical Mechanical Polishing (CMP) and cleaning to finally obtain a single crystal silicon wafer. For the single crystal silicon wafers, the surface topography serves as a key parameter in determining their quality. And the surface roughness is an important performance parameter in surface topography parameters of the wafer.

[0004] Based on the processes in the manufacture of the wafer, after the single crystal silicon ingot is cut by a wire saw device to obtain a raw wafer, the raw wafer has an initial surface state, and the subsequent processes, e.g., lapping, etching, grinding, CMP and cleaning, are merely used to gradually repair surface damages on the basis of the initial surface state. Based on the above, in order to obtain the single crystal silicon wafer with an excellent surface roughness index, process optimization needs to be started in the wire sawing process, so as to improve the surface roughness of the raw

wafer obtained through the wire sawing process, thereby to improve the surface roughness index of the finally-obtained single crystal silicon wafer.

[0005] In the wire sawing process, uniformity of a size of an abrasive particle serves as a process parameter for representing a wire sawing capability. To be specific, the abrasive particles are sampled to obtain their sizes, and the overall wire sawing capability of the abrasive particles is estimated based on statistics of the sizes. However, it is impossible to verify the estimation accuracy of the overall real wire sawing capability of the abrasive particles based on the sampling mode and statistical results derived from the acquisition process of the uniformity of abrasive particle size as described above.

SUMMARY

[0006] An object of the present disclosure is to provide a wafer, a method and an apparatus for improving roughness of the wafer, a device, and a medium, so as to take a geometric similarity between a shape of an abrasive particle and a regular polyhedron as an estimation index of a wire sawing capability, and optimize a wire sawing process based on the estimation index, thereby to reduce surface roughness of the wafer.

[0007] The technical solutions of the present disclosure are implemented as follows.

[0008] In a first aspect, the present disclosure provides in some embodiments a method for improving roughness of a wafer, including: in a case that roughness of a raw wafer obtained through a wire sawing process within a target wavelength range is greater than or equal to a predetermined roughness threshold, determining an index value for representing a wire sawing capability of a currently-used wire sawing slurry based on a geometric similarity between an abrasive particle in the currently-used wire sawing slurry for the wire sawing process and a regular polyhedron; and in a case that the index value is smaller than or equal to a predetermined performance threshold,

replenishing a new wire sawing slurry into an equipment for performing the wire sawing process.

[0009] In a second aspect, the present disclosure provides in some embodiments an apparatus for improving roughness of a wafer, including a determination member, a comparison member, and a process improvement member. The determination member is configured to, in a case that roughness of a raw wafer obtained through a wire sawing process within a target wavelength range is greater than or equal to a predetermined roughness threshold, determine an index value for representing a wire sawing capability of a currently-used wire sawing slurry based on a geometric similarity between an abrasive particle in the currently-used wire sawing slurry for the wire sawing process and a regular polyhedron; the comparison member is configured to compare the index value with a predetermined performance threshold, and in a case that the index value is smaller than or equal to the predetermined performance threshold, trigger the process improvement member; and the process improvement member is configured to replenish a new wire sawing slurry into an equipment for performing the wire sawing process.

[0010] In a third aspect, the present disclosure provides in some embodiments a computing device, including a processor and a memory. The processor is configured to execute an instruction stored in the memory to implement the method in the first aspect.

[0011] In a fourth aspect, the present disclosure provides in some embodiments a computer-readable storage medium storing therein at least one instruction. The at least one instruction is executed by a processor to implement the method in the first aspect.

[0012] In a fifth aspect, the present disclosure provides in some embodiments a wafer obtained through a wire sawing process improved using the method in the first aspect. The roughness of the wafer within a target wavelength range includes at least one of: in a case that the target wavelength range is 0 to 1.8 μm , the roughness is 0.01 nm to 1 nm; in a case that the target wavelength range is 1.8 μm to 22 μm , the roughness is 1 nm to 3 nm; and in a case that the target wavelength range is 22 μm to 20 mm, the roughness is 3 nm to 30 nm.

[0013] According to the wafer, the method and the apparatus for improving the roughness of the wafer, the device and the medium in the embodiments of the present disclosure, in a case that the roughness of the raw wafer obtained through the wire sawing process within the target wavelength range is greater than or equal to the predetermined roughness threshold, the index value for representing the wire sawing capability of the currently-used wire sawing slurry is determined based on the geometric similarity between the abrasive particle in the currently-used wire sawing slurry for the wire sawing process and the regular polyhedron, and in a case that the index value is smaller than or equal to the predetermined performance threshold, the new wire sawing slurry is replenished into the equipment for performing the wire sawing process. As a result, it is able to accurately evaluate the wire sawing performance of the abrasive particle, replenish the new wire sawing slurry in time in a case that the wire sawing performance is deteriorated, and maintain the wire sawing performance of the wire sawing slurry at an excellent level, thereby to reduce the surface roughness of the wafer.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The following drawings are provided to facilitate the understanding of the features and advantages of the present disclosure. The drawings are not drawn according to an actual scale, and some features may be zoomed in or out to display details of specific members. In the drawings:

[0015] Fig. 1 is a schematic view showing a multi-wire sawing device according to an embodiment of the present disclosure;

[0016] Fig. 2 is a flow chart of a method for improving roughness of a wafer according to an embodiment of the present disclosure;

[0017] Fig. 3 is a schematic view showing a microscopic image of abrasive particles according to an embodiment of the present disclosure;

[0018] Fig. 4 is a schematic view showing a situation where a filter slides on a surface of the wafer according to an embodiment of the present disclosure;

[0019] Fig. 5 is a schematic view showing to-be-analyzed regions obtained through dividing according to an embodiment of the present disclosure;

[0020] Fig. 6 is a schematic view showing an apparatus for improving roughness of a wafer according to an embodiment of the present disclosure; and

[0021] Fig. 7 is a schematic view showing a computing device according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0022] The technical solutions of the present disclosure will be described hereinafter in a clear and complete manner in conjunction with the drawings.

[0023] Fig. 1 illustratively shows a multi-wire sawing equipment 1 for the technical solutions of the present disclosure, and the equipment 1 includes a wire sawing unit 11 and a support unit 12. In some embodiments of the present disclosure, the wire sawing unit 11 is arranged below the support unit 12 in a vertical direction. In some other embodiments of the present disclosure, the wire sawing unit 11 may also be arranged above the support unit 12 in the vertical direction, which will not be particularly defined herein.

[0024] The wire sawing unit 11 includes a plurality of reels 111, a cutting wire 112 and wire sawing slurry supply units 113, and the cutting wire 112 is wound onto the reels 111 to form an array consisting of a plurality of cutting wire segments parallel to each other. The following description will be given in a case that there are two reels 111 in Fig. 1. The two reels 111 are arranged opposite to each other in such a manner that axes of the reels 111 are parallel to each other. The two wire sawing slurry supply units 113 are arranged right above the two reels 111 respectively, and configured to spray a wire sawing slurry to the reels 111 and the cutting wire 112. The wire sawing slurry is a liquid medium including suspended abrasive particles.

[0025] The reel 111 and the cutting wire 112 reciprocally move toward and away from the support unit 12 in a direction as indicated by a solid arrow in Fig. 1, at a velocity of 10 m/s to 15 m/s. The support unit 12 is configured to support and fix a to-

be-processed silicon ingot S, and it includes a base 121 and an intermediate member 122. The to-be-processed silicon ingot S is fixed onto the base 121 via the intermediate member 122. For example, a circumferential surface of the to-be-processed silicon ingot is adhered to a lower surface of the base 121, so that the to-be-processed silicon ingot is fixed to the base 121.

[0026] For the wire sawing equipment 1 in Fig. 1, the support unit 12 moves toward the array of cutting wire segments in the vertical direction, so that the to-be-processed silicon ingot moves close to the arrays of cutting wire segments. In a case that the arrays of cutting wire segments are in contact with the to-be-processed silicon ingot S, each array of cutting wire segments moves along its extension direction and the support unit 12 continues to move toward the array of cutting wire segments in the vertical direction, so as to cut the to-be-processed silicon ingot S. It should be appreciated that, the support unit 12 is moved via a lifting unit (not shown). Of course, the support unit 12 may also be moved in any other ways according to the practical need and an operating scenario, which will not be particularly defined herein.

[0027] A plurality of slots 111A is formed in the circumferential surface of the reel 111 for guiding and fixing the cutting wire 112, so as to enable the cutting wire to maintain a stable tension and a stable position during the wire sawing. Usually, the slots 111A are distributed evenly on the circumferential surface of the reel 111.

[0028] Based on the multi-wire sawing equipment 1 in Fig. 1, a microcosmic mechanism between the abrasive particles in the wire sawing slurry carried on the cutting wire 112 made of such a material as tungsten steel and the to-be-processed silicon ingot S during the reciprocation of the cutting wire 112 is called as a “rolling-indenting” model, i.e., the abrasive particle is embedded into a surface of the to-be-processed silicon ingot S under the effect of the cutting wire and the wire sawing slurry, and during the displacement of the cutting wire and the wire sawing slurry, a local region of the surface of the to-be-processed silicon ingot S is levered up due to a leverage effect with a portion of the abrasive particle not embedded into the surface of

the to-be-processed silicon ingot S as an arm of force, so as to remove a part of the to-be-processed silicon ingot S at the local region.

[0029] Based on the above-mentioned microcosmic mechanism, the removal of a part of the to-be-processed silicon ingot S depends on a capability of embedding the abrasive particle into the surface of the to-be-processed silicon ingot S. Silicon is fragile at a normal temperature, so the abrasive particle should not be embedded into the surface of the to-be-processed silicon ingot S too deep, otherwise a large-area damage easily occurs after the lever-up. In this way, although a removing rate of the material increases, a very bad surface state occurs.

[0030] It should be appreciated that, the leverage effect depends on a length of the arm of force, and it is found that an ideal abrasive particle should have an appropriate edge length. In addition, it is also found that a probability of embedding the abrasive particle into the surface of the to-be-processed silicon ingot S increases through adding the quantity of angles. Hence, the ideal abrasive particle should have solid angles (i.e., vertices) as many as possible, in addition to the appropriate edge length.

[0031] For a three-dimensional body, in order to provide the solid angles as many as possible and provide each edge with a large length, only a regular polyhedron simultaneously meets the above requirements. However, during the actual manufacture of the abrasive particles, it is very difficult to obtain the abrasive particle with a regular polyhedral shape due to the limit of control conditions in dynamics and thermodynamics. In actual use, the abrasive particle is of an irregular shape.

[0032] Based on the above, the present disclosure intends to describe a wire sawing capability of the abrasive particle by means of a deviation degree between the shape of the abrasive particle and a regular polyhedron structure, so as to accurately evaluate the wire sawing capability of the abrasive particle, and improve a wire sawing process based on the wire sawing capability of the abrasive particle, thereby to improve roughness of a wafer. Fig. 2 shows a method for improving roughness of a wafer, and the method includes Steps S210 and S220.

[0033] Step S210: in a case that roughness of a raw wafer obtained through a wire sawing process within a target wavelength range is greater than or equal to a predetermined roughness threshold, determining an index value for representing a wire sawing capability of a currently-used wire sawing slurry based on a geometric similarity between an abrasive particle in the currently-used wire sawing slurry for the wire sawing process and a regular polyhedron.

[0034] In the embodiments of the present disclosure, the uniformity of surface topography of the wafer is represented by a difference among heights at points on a surface of the wafer, and generally the heights at the points on the surface of the wafer fluctuate. Based on the above, in the embodiments of the present disclosure, from the perspective of waves, this fluctuation is considered to be caused by superimposition of wave signals with different wavelengths. The smaller the wavelength of the wave signal, the smaller the size of a region where the fluctuation in the heights occurs; and the larger the wavelength of the wave signal, the larger the size of the region where the fluctuation in the heights occurs.

[0035] Based on the above, in order to evaluate or measure the roughness in a smaller region, filtration is performed on the fluctuation using a size of a region where the roughness is expected to be measured, so as to obtain wave signal data within a wavelength range corresponding to the region where the roughness is expected to be measured, and obtain the roughness of the wafer based on the wave signal data with the size of the region as a standard.

[0036] After obtaining the roughness of the raw wafer obtained through the wire sawing process within the target wavelength range, the predetermined roughness threshold is used to represent whether the roughness is good or not. In a case that the target wavelength range is 22 μm to 20 mm, the predetermined roughness threshold is set as 30 nm. In other words, in a case that the roughness of the raw wafer within the target wavelength range is greater than or equal to 30 nm, it means that a wire sawing capability of the multi-wire sawing equipment 1 is deteriorated seriously. The deterioration of the wire sawing capability of the multi-wire sawing device may be

caused by the deterioration of the wire sawing capability of the wire sawing slurry, or the other components of the multi-wire sawing equipment 1 or other process parameters in the wire sawing process. Hence, in a case that the wire sawing capability of the multi-wire sawing equipment 1 is deteriorated seriously, in the embodiments of the present disclosure, the wire sawing capability of the wire sawing slurry is evaluated, and after determining that the wire sawing capability of the wire sawing slurry is deteriorated, Step S220 is performed to improve the wire sawing capability of the wire sawing slurry, so as to improve the wire sawing capability of the multi-wire sawing equipment 1, thereby to improve the roughness of the wafer.

[0037] It should be appreciated that, the wire sawing capability of the wire sawing slurry depends on the abrasive particles in the wire sawing slurry. In a case that a wire sawing capability of the abrasive particle decreases, the wire sawing capability of the wire sawing slurry also decreases. Based on the above-mentioned requirements on a shape of the ideal abrasive particle and the fact that the regular polyhedron structure meets the requirement, in the embodiments of the present disclosure, the wire sawing capability of the abrasive particle may be described on the basis of a deviation degree between the shape of the abrasive particle and the regular polyhedron structure. In other words, the larger the deviation degree between the shape of the abrasive particle and the regular polyhedron structure, the lower the wire sawing capability of the wire sawing slurry; and the smaller the deviation degree between the shape of the abrasive particle and the regular polyhedron structure, the higher the wire sawing capability of the wire sawing slurry. In some illustrative embodiments of the present disclosure, for the abrasive particle in the currently-used wire sawing slurry, the index value for representing the wire sawing capability of the wire sawing slurry may be determined based on the geometric similarity between the abrasive particle and the regular polyhedron.

[0038] Step S220: in a case that the index value is smaller than or equal to a predetermined performance threshold, replenishing a new wire sawing slurry into an equipment for performing the wire sawing process.

[0039] In the embodiments of the present disclosure, a deterioration degree of the wire sawing capability of the wire sawing slurry is evaluated based on the predetermined performance threshold. For example, in a case that the index value obtained in Step S210 for representing the wire sawing capability of the currently-used wire sawing slurry is smaller than or equal to the predetermined performance threshold, it means that the wire sawing capability of the abrasive particle in the wire sawing slurry is deteriorated seriously. In a case that the wire sawing slurry is used continuously, the roughness of the raw wafer obtained through the wire sawing process within the target wavelength range may increase. Hence, it is necessary to improve the abrasive particle whose wire sawing capability is deteriorated. During the wire sawing, usually the wire sawing slurry is recycled, and in a case that the wire sawing capability of the abrasive particles in the wire sawing slurry is deteriorated seriously, it is necessary to replenish a new wire sawing slurry. In some illustrative embodiments of the present disclosure, in order to replenish the new wire sawing slurry, the multi-wire sawing equipment for performing the wire sawing process is stopped, and the wire sawing slurry in a container of the multi-wire sawing device is discharged, and then the new wire sawing slurry is added into the container. In some illustrative embodiments of the present disclosure, in order to prevent the production efficiency from being adversely affected in a case that the device is stopped frequently, the newly-added wire sawing slurry is completely mixed with the existing wire sawing slurry in the container, so as to increase the wire sawing capability which has already been deteriorated seriously to the wire sawing capability corresponding to the predetermined performance threshold.

[0040] For the technical solution in Fig. 2, in a case that the roughness of the raw wafer obtained through the wire sawing process within the target wavelength range is greater than or equal to the predetermined roughness threshold, the index value for representing the wire sawing capability of the currently-used wire sawing slurry is determined based on the geometric similarity between the abrasive particle in the currently-used wire sawing slurry for the wire sawing process and the regular polyhedron, and in a case that the index value is smaller than or equal to the

predetermined performance threshold, the new wire sawing slurry is replenished into the equipment for performing the wire sawing process. As a result, it is able to accurately evaluate the wire sawing performance of the abrasive particle, replenish the new wire sawing slurry in time in a case that the wire sawing performance is deteriorated, and maintain the wire sawing performance of the wire sawing slurry at an excellent level, thereby to reduce the surface roughness of the wafer.

[0041] For the technical solution in Fig. 2, in some embodiments of the present disclosure, a procedure of obtaining the geometric similarity between the abrasive particle in the currently-used wire sawing slurry for the wire sawing process and the regular polyhedron includes: scanning the currently-used wire sawing slurry through a scanning electron microscope, to collect microscopic images of a plurality of abrasive particles in the currently-used wire sawing slurry; performing image analysis on the collected microscopic image of each abrasive particle, to obtain a length of each side, a maximum diagonal length and the quantity of solid angles of each abrasive particle; and determining the geometric similarity between each abrasive particle and the regular polyhedron based on the length of each side and the quantity of solid angles of each abrasive particle.

[0042] To be specific, during the wire sawing, the wire sawing slurry is mixed evenly through mechanical stirring, and then evenly dispersed onto the cutting wire. In the embodiments of the present disclosure, the currently-used wire sawing slurry is scanned using the Scanning Electron Microscope (SEM) at a predetermined magnification (scale) and a predetermined step, so as to obtain the plurality of microscopic images of the abrasive particles. Fig. 3 obviously shows a microscopic image of three abrasive particles. The collected microscopic image of each abrasive particle is analyzed using a deep learning model which has been trained to perform image instance segmentation, e.g., mask-RCNN, so as to obtain three shape parameters of each abrasive particle, e.g., the length of each side, the maximum diagonal length, and the quantity of solid angles (vertices) of each abrasive particle.

[0043] Among the above-mentioned three shape parameters, the length of each side and the quantity of solid angles are used to represent a shape similarity between the abrasive particle and the regular polyhedron. Based on the above, in the embodiments of the present disclosure, the geometric similarity between each abrasive particle and the regular polyhedron is calculated based on a difference between the quantity of solid angles of each abrasive particle and a variance of the lengths of all the sides. To be specific, a geometric similarity index between the abrasive particle and the regular polyhedron is defined as LR for representing a size of a similarity between a geometric shape of the abrasive particle and a geometric shape of the regular polyhedron. For any abrasive particle, its LR is calculated through $LR = c - \sigma_{(a_i)}^2$, where c represents the quantity of solid angles of the abrasive particle, a_i represents the quantity of sides of the abrasive particle, and $\sigma_{(a_i)}^2$ represents the variance of the lengths of all the sides of the abrasive particle. It should be appreciated that, the larger the value of c and the smaller the value of $\sigma_{(a_i)}^2$, the larger the value of LR, and the higher the geometric similarity between the abrasive particle and the regular polyhedron.

[0044] Based on the above, in some illustrative embodiments of the present disclosure, subsequent to obtaining the geometric similarity between the abrasive particle and the regular polyhedron, Step S210 of determining the index value for representing the wire sawing capability of the currently-used wire sawing slurry based the geometric similarity between the abrasive particle in the currently-used wire sawing slurry for the wire sawing process and the regular polyhedron includes: obtaining a median of the geometric similarities between all the abrasive particles and the regular polyhedron; obtaining a variance of the maximum diagonal lengths of all the abrasive particles; and obtaining the index value for representing the wire sawing capability of the currently-used wire sawing slurry based on the median of the geometric similarities between all the abrasive particles and the regular polyhedron and the variance of the maximum diagonal lengths of all the abrasive particles.

[0045] Based on the above, to be specific, after obtaining the LR of each abrasive particle, the LRs of the abrasive particles in all the microscopic images are counted to obtain sizes of the geometric similarities LRS between all the abrasive particles and the regular polyhedron. For example, the LRs of all the abrasive particles are normalized, and the median is selected as the LRS. The LRS also represents a regular polyhedron similarity of the currently-used wire sawing slurry, and it is a parameter for representing the wire sawing capability of the wire sawing slurry.

[0046] In addition, in the embodiments of the present disclosure, for each abrasive particle, a maximum distance between pixels in the microscopic image is determined as the maximum Diagonal Length (DL) of the abrasive particle. Next, the DLs of all the abrasive particles in all the microscopic images are counted and normalized, and a variance of the normalized DLs is taken as another parameter for representing the wire sawing capability of the wire sawing slurry, e.g., this parameter is defined as Diagonal Length Statistic (DLS). To be specific, the DLS is calculated

through $DLS = \sigma^2_{(DL_k)}$, where DL_k represents normalized DLs of all the abrasive particles, and $\sigma^2_{(DL_k)}$ represents the variance of the normalized DLs of all the abrasive particles.

[0047] Based on the LRS and the DLS, the index value SP for representing the wire sawing capability of the currently-used wire sawing slurry is calculated through $SP = LRS/DLS$.

[0048] Based on the above-mentioned formula, in a case that the geometric shapes of the abrasive particles are very close to a geometric shape of the regular polyhedron, a value of the LRS increases, and in a case that the abrasive particles have a uniform size, a value of DLS decreases. Based on the above two parameters for representing the wire sawing capability of the wire sawing slurry, in the above two situations, the index value SP for reflecting or representing the wire sawing capability of the wire sawing slurry is relatively large.

[0049] For the technical solution in Fig. 2, in some embodiments of the present disclosure, the method further includes: for each sampling point on a surface of the raw wafer, obtaining original measurement data about a height of the surface of the raw wafer at the sampling point through single-point measurement; obtaining a wave signal at each sampling point within the target wavelength range using a filter corresponding to the target wavelength range based on the original measurement data at all the sampling points on the surface of the raw wafer; and determining the roughness of the raw wafer within the target wavelength range based on statistics of amplitudes of the wave signals at all the sampling points within the target wavelength range.

[0050] Based on the above, to be specific, the single-point measurement is just a scheme in which the measurement data about merely one sampling point is measured in a single measurement procedure. In some illustrative embodiments of the present disclosure, a contact-type measurement scheme is adopted, e.g., a probe is in contact with the surface of the raw wafer and moves horizontally along the surface of the raw wafer. During the horizontal movement, longitudinal displacement occurs for the probe due to a height difference of the surface of the raw wafer. The longitudinal displacement is detected by a displacement sensor and converted into height data about the surface of the raw wafer, i.e., the original measurement data about the height of the surface of the wafer. In some other illustrative embodiments of the present disclosure, a non-contact-type measurement scheme, e.g., capacitive measurement or laser focusing measurement, may also be adopted.

[0051] After measuring each sampling point on the surface of the raw wafer using the single-point measurement, the original measurement data about all the sampling points may reflect the height difference between the sampling points, and the original measurement data at all sampling points is considered as a three-dimensional fluctuation from the entire surface of the wafer. For the fluctuation, amplitudes of the wave signals superimposed to form the fluctuation and having different wavelengths are used to represent a height difference in a region having a size corresponding to the wavelength.

[0052] In some embodiments of the present disclosure, the target wavelength range includes at least one of 0 to 1.8 μm , 1.8 μm to 22 μm , and 22 μm to 20 mm. Taking the target wavelength range of 22 μm to 20 mm as an example, it includes an upper limit and a lower limit.

[0053] In some embodiments of the present disclosure, in order to obtain the wave signal at each sampling point within the target wavelength range, at first a wave signal whose wavelength is greater than the upper limit is filtered from the fluctuation using a low-pass filter function, and then a wave signal whose wavelength is smaller than the lower limit is filtered from the fluctuation using a high-pass filter function, to finally obtain the wave signal within the target wavelength range. To be specific, the filter is a circular filter consisting of double Gaussian filter functions. A first Gaussian filter function GLP1 is a Gaussian low-pass filter function whose low-pass filter range covers the upper limit of the target wavelength range, a second Gaussian filter function GLP2 is a Gaussian low-pass filter function whose low-pass filter range covers the lower limit of the target wavelength range, and a high-pass filter function is obtained through $(1-\text{GLP2})$. Based on the first Gaussian filter function and the second Gaussian filter function, the circular filter GDHP is represented as $\text{GDHP}=\text{GLP1} (1-\text{GLP2})$. In the embodiments of the present disclosure, taking the above circular filter as an example, as shown in Fig. 4, the circular filter indicated by an arrow slides on the surface of the raw wafer along the sampling points, and the original measurement data about a sampling point at a center of the circular filter and the other sampling points within an operating range of the circular filter is filtered by the circular filter to obtain the wave signal at each sampling point within the target wavelength range.

[0054] It should be appreciated that, the topography changes more dramatically at a position closer to an edge of the surface of the wafer. In order to accurately capture the dramatical change in the topography, the operating range of the circular filter in a case that the sampling point is close to the edge of the surface of the wafer should be smaller than the operating range of the circular filter in a case that the sampling point is close to a center of the surface of the wafer. In other words, in a case that the sampling

point gradually moves away from the center of the surface of the wafer, the operating range of the corresponding filter should decrease, which is also called as contraction. Hence, a radius of the operating range of the filter is determined based on a distance between the sampling point and the center of the raw wafer.

[0055] In the embodiments of the present disclosure, a critical distance is set to determine whether the sampling point is close to the center of the surface of the wafer or close to the edge of the surface of the wafer. In a case that the distance between the sampling point and the center of the surface of the raw wafer is smaller than or equal to the critical distance, the radius of the operating range of the filter is a first radius, and in a case that the distance between the sampling point and the center of the surface of the raw wafer is greater than the critical distance, the radius of the operating range of the filter is a second radius. The first radius and the second radius are both determined based on the upper limit of the target wavelength range, and the first radius is greater than the second radius.

[0056] Based on the above, to be specific, the contraction is stepwise, i.e., in a case that the distance between the sampling point and the center of the surface of the raw wafer is greater than the critical distance, the second radius is set as a constant value smaller than the first radius. Alternatively, the contraction may also be gradual, i.e., the second radius gradually decreases along with an increase in the distance between the sampling point and the center of the surface of the raw wafer. To be specific, in a case that the distance between the sampling point and the center of the surface of the raw wafer is greater than the critical distance, the second radius is a constant value smaller than the first radius, or the second radius is negatively correlated with the distance between the sampling point and the center of the surface of the raw wafer.

[0057] Based on the above, after obtaining the wave signals at all the sampling points within the target wavelength range through filtering, in some illustrative embodiments of the present disclosure, the determining the roughness of the raw wafer within the target wavelength range based on the statistics of the amplitudes of the wave signals at all the sampling points within the target wavelength range includes: dividing

the raw wafer into a plurality of to-be-analyzed regions; calculating a range of the amplitudes of the wave signals within the target wavelength range in each to-be-analyzed region based on the amplitudes of the wave signals within the target wavelength range at the sampling points in each to-be-analyzed region; and calculating the roughness of the raw wafer within the target wavelength range based on the ranges of the amplitudes of the wave signals within the target wavelength range in all the to-be-analyzed regions.

[0058] Based on the above, as shown in Fig. 5, after an edge region of the raw wafer is removed through EE, the remaining raw wafer is divided into square regions based on a predetermined size, e.g., 10 mm* 10 mm, so as to obtain complete to-be-analyzed regions and incomplete to-be-analyzed regions at an edge of the remaining wafer obtained after the edge region is removed through EE. The two types of to-be-analyzed regions form the above-mentioned to-be analyzed region.

[0059] It should be appreciated that, the wave signals within the target wavelength range at all the sampling points on the surface of the wafer include all information capable of representing the surface topography (i.e., roughness) of the wafer in the region corresponding to the target wavelength range, and the information is represented by the statistics of the amplitudes, e.g., an average value, an extreme value, an extreme value at a predetermined area ratio, a range, a variance, a standard deviation, a median or a modal number of the above-mentioned amplitudes.

[0060] In the embodiments of the present disclosure, taking the range as an example, the statistics of the amplitudes of the wave signals within the target wavelength range in each to-be-analyzed region is a range of the amplitudes of the wave signals within the target wavelength range at the sampling points and interpolation points in each to-be-analyzed region. Correspondingly, the roughness index of the raw wafer within the target wavelength range is an average value of the ranges of the amplitudes of the wave signals within the target wavelength range in all the to-be-analyzed regions.

[0061] Based on the above technical solutions, the following description will be given in conjunction with three specific embodiments.

[0062] In a first embodiment, taking the target wavelength range of 22 μm to 20 mm as an example, for a cycle duration of the wire sawing slurry, based on the above technical solutions, Table 1 shows the roughness of the raw wafer obtained through the wire sawing process within the target wavelength range and the index value SP for representing the wire sawing capability of the currently-used wire sawing slurry.

Cycle duration of wire sawing slurry	SP	Roughness within target wavelength range
0h	7.7	5.7nm
5h	5.8	11.8nm
10h	3.1	18.4nm
15h	0.9	31.3nm
20h	0.4	37.8nm
25h	0.07	103.6nm
30h	0.07	121.8nm

Table 1

[0063] As shown in Table 1, after a cycle duration of 10 hours, the index value SP decreases significantly (from 3.1 to 0.9), and correspondingly, the roughness within the target wavelength range increases significantly (from 18.4 to 31.3). Hence, in the wire sawing process, the new wire sawing slurry should be added after the wire sawing slurry is used for 10 hours.

[0064] In addition, in this embodiment of the present disclosure, based on the above, the new wire sawing slurry is added on the basis of the existing wire sawing slurry after 10 hours (i.e., a 15th hour) and 20 hours (a 25th hour). Table 2 shows the roughness within the target wavelength range and the SP based on the above technical solution.

Cycle duration of wire sawing	SP	Roughness within target
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slurry		wavelength range
0h	7.7	5.7nm
5h	5.8	11.8nm
10h	3.1	18.4nm
15h+1/2 new wire sawing slurry	2.9	21.3nm
20h	1.8	29.4nm
25h+1/2 new wire sawing slurry	2.2	26.7nm

Table 2

[0065] As shown in Table 2, in a case that the wire sawing capability of the wire sawing slurry is deteriorated, the new wire sawing slurry is added, so as to improve the wire sawing capability of the entire wire sawing slurry.

[0066] Based on the above technical solutions and the specific embodiment, the wafer obtained through the wire sawing process improved by the above-mentioned method has roughness of 3 nm to 30 nm in a case that the target wavelength range is 22 μm to 20 mm. In a second embodiment, taking the target wavelength range of 1.8 μm to 22 μm as an example, for a cycle duration of the wire sawing slurry, based on the above technical solutions, Table 3 shows the roughness of the raw wafer obtained through the wire sawing process within the target wavelength range and the index value SP for representing the wire sawing capability of the currently-used wire sawing slurry.

Cycle duration of wire sawing slurry	SP	Roughness within target wavelength range
0h	7.7	1.8 nm
2h	7.1	2.2 nm
4h	5.7	2.9 nm
6h	4.8	5.3nm
8h	3.7	9.4nm

10h	3.1	11nm
12h	2.1	13.8nm

Table 3

[0067] As shown in Table 3, after a cycle duration of 4 hours, the index value SP decreases to 4.8, and correspondingly, the roughness within the target wavelength range increases significantly (from 2.9 to 5.3). Hence, in the wire sawing process, the new wire sawing slurry should be added after the wire sawing slurry is used for 4 hours.

[0068] In addition, in this embodiment of the present disclosure, based on the above, the new wire sawing slurry is added on the basis of the existing wire sawing slurry in a 4th hour and a 10th hour. Table 4 shows the roughness within the target wavelength range and the SP based on the above technical solution.

Cycle duration of wire sawing slurry	SP	Roughness within target wavelength range
0h	7.7	1.8 nm
2h	7.1	2.2nm
4h+1/2 new wire sawing slurry	6.8	2.5 nm
6h	6.2	2.9 nm
8h	5.4	3 nm
10h+1/2 new wire sawing slurry	5.1	3 nm

Table 4

[0069] As shown in Table 4, in a case that the wire sawing capability of the wire sawing slurry is deteriorated, the new wire sawing slurry is added, so as to improve the wire sawing capability of the entire wire sawing slurry.

[0070] Based on the above technical solutions and the specific embodiment, the wafer obtained through the wire sawing process improved by the above-mentioned method has roughness of 1 nm to 3 nm in a case that the target wavelength range is 1.8 μm to 22 μm .

[0071] In a third embodiment, taking the target wavelength range of 0 μm to 1.8 μm as an example, for a cycle duration of the wire sawing slurry, based on the above technical solutions, Table 5 shows the roughness of the raw wafer obtained through the wire sawing process within the target wavelength range and the index value SP for representing the wire sawing capability of the currently-used wire sawing slurry.

Cycle duration of wire sawing slurry	SP	Roughness within target wavelength range
0h	7.7	0.4 nm
1h	7.3	0.6 nm
2h	7.1	0.8 nm
3h	6.8	0.9 nm
4h	5.7	1.8 nm
5h	5	2.2 nm
6h	4.8	2.7 nm

Table 5

[0072] As shown in Table 5, after a cycle duration of 4 hours, the index value SP decreases to 5.7, and correspondingly, the roughness within the target wavelength range increases significantly to 1.8 nm. Hence, in the wire sawing process, the new wire sawing slurry should be added after the wire sawing slurry is used for 4 hours.

[0073] In addition, in this embodiment of the present disclosure, based on the above, the new wire sawing slurry is added on the basis of the existing wire sawing slurry in a 4th hour. Table 6 shows the roughness within the target wavelength range and the SP based on the above technical solution.

Cycle duration of wire sawing slurry	SP	Roughness within target wavelength range
0h	7.7	0.4 nm
1h	7.3	0.6 nm
2h	7.1	0.8 nm

3h	6.8	0.9 nm
4h+1/2 new wire sawing slurry	6.6	1 nm

Table 6

[0074] As shown in Table 6, in a case that the wire sawing capability of the wire sawing slurry is deteriorated, the new wire sawing slurry is added, so as to improve the wire sawing capability of the entire wire sawing slurry.

[0075] Based on the above technical solutions and the specific embodiment, the wafer obtained through the wire sawing process improved by the above-mentioned method has roughness of 0.01 nm to 1 nm in a case that the target wavelength range is 0 μm to 1.8 μm .

[0076] Based on a same inventive concept as the above-mentioned technical solution, as shown in Fig. 6, the present disclosure provides an apparatus 60 for improving roughness of a wafer, which includes a determination member 601, a comparison member 602 and a process improvement member 603. The determination member 601 is configured to, in a case that roughness of a raw wafer obtained through a wire sawing process within a target wavelength range is greater than or equal to a predetermined roughness threshold, determine an index value for representing a wire sawing capability of a currently-used wire sawing slurry based on a geometric similarity between an abrasive particle in the currently-used wire sawing slurry for the wire sawing process and a regular polyhedron; the comparison member 602 is configured to compare the index value with a predetermined performance threshold, and in a case that the index value is smaller than or equal to the predetermined performance threshold, trigger the process improvement member 603; and the process improvement member 603 is configured to replenish a new wire sawing slurry into an equipment for performing the wire sawing process.

[0077] In some embodiments of the present disclosure, the determination member 601 is further configured to: scan the currently-used wire sawing slurry through a scanning electron microscope, to collect microscopic images of a plurality of abrasive

particles in the currently-used wire sawing slurry; perform image analysis on the collected microscopic image of each abrasive particle, to obtain a length of each side and the quantity of solid angles of each abrasive particle; and determine the geometric similarity between each abrasive particle and the regular polyhedron based on the length of each side and the quantity of solid angles of each abrasive particle.

[0078] In some embodiments of the present disclosure, the determination member 601 is further configured to: calculate the geometric similarity between each abrasive particle and the regular polyhedron based on a difference between the quantity of solid angles of each abrasive particle and a variance of the lengths of all the sides.

[0079] In some embodiments of the present disclosure, the determination member 601 is further configured to: perform image analysis on the collected microscopic image of each abrasive particle, to obtain a maximum diagonal length of each abrasive particle. Correspondingly, the determination member 601 is configured to: obtain a median of the geometric similarities between all the abrasive particles and the regular polyhedron; obtain a variance of the maximum diagonal lengths of all the abrasive particles; and obtain the index value for representing the wire sawing capability of the currently-used wire sawing slurry based on the median of the geometric similarities between all the abrasive particles and the regular polyhedron and the variance of the maximum diagonal lengths of all the abrasive particles.

[0080] In some embodiments of the present disclosure, the determination member 601 is configured to: calculate the index value for representing the wire sawing capability of the currently-used wire sawing slurry based on a ratio of the median of the geometric similarities between all the abrasive particles and the regular polyhedron to the variance of the maximum diagonal lengths of all the abrasive particles.

[0081] In some embodiments of the present disclosure, the determination member 601 is further configured to: for each sampling point on a surface of the raw wafer, obtain original measurement data about a height of the surface of the raw wafer at the sampling point through single-point measurement; obtain a wave signal at each sampling point within the target wavelength range using a filter corresponding to the

target wavelength range based on the original measurement data at all the sampling points on the surface of the raw wafer; and determine the roughness of the raw wafer within the target wavelength range based on statistics of amplitudes of the wave signals at all the sampling points within the target wavelength range.

[0082] In some embodiments of the present disclosure, the filter is a circular filter and includes double Gaussian filter functions; a radius of an operating range of the filter is determined based on a distance between the sampling point and a center of the raw wafer, and in a case that the distance between the sampling point and the center of the raw wafer is smaller than or equal to a critical distance, the radius of the operating range of the filter is a first radius; in a case that the distance between the sampling point and the center of the raw wafer is greater than the critical distance, the radius of the operating range of the filter is a second radius; and the first radius and the second radius are determined based on an upper limit of the target wavelength range, and the first radius is greater than the second radius.

[0083] In some embodiments of the present disclosure, the determination member 601 is further configured to: divide the raw wafer into a plurality of to-be-analyzed regions; calculate a range of the amplitudes of the wave signals within the target wavelength range in each to-be-analyzed region based on the amplitudes of the wave signals within the target wavelength range at the sampling points in each to-be-analyzed region; and calculate the roughness of the raw wafer within the target wavelength range based on the ranges of the amplitudes of the wave signals within the target wavelength range in all the to-be-analyzed regions.

[0084] In some embodiments of the present disclosure, the target wavelength range includes at least one of 0 to 1.8 μm , 1.8 μm to 22 μm , and 22 μm to 20 mm.

[0085] It should be appreciated that, the implementation of the function of each member in the apparatus may refer to the implementation of the corresponding step in the above-mentioned method and the embodiments thereof, and thus will not be particularly defined herein.

[0086] Fig. 7 is a block diagram of a computing device according to an illustrative embodiment of the present disclosure. In some illustrative embodiments of the present disclosure, the computing device 70 includes at least one of a smart phone, a smart watch, a desktop computer, a notebook, a virtual reality terminal, an augmented reality terminal, a wireless terminal, and a laptop computer. The computing device 70 has a communication function, and it may access a wired network or a wireless network. The computing device 70 generally refers to one of a plurality of terminals, and more or fewer terminals may be provided. In some illustrative embodiments of the present disclosure, the computing device 70 receives data based on the wired network or the wireless network. It should be appreciated that, the computing device 70 is used to perform calculation and processing in the technical solution of the present disclosure, which will not be particularly defined herein.

[0087] As shown in Fig. 7, the computing device includes one or more of a processor 710 and a memory 720.

[0088] Optionally, the processor 710 is coupled to each component of the entire computing device via various interfaces and lines, and executes various functions of the computing device and process data through running or executing instructions, program, code sets or instruction set stored in the memory 720, and calling data stored in the memory 720.

[0089] In the embodiments of the present disclosure, the processor 710 is configured to execute the instruction stored in the memory, so as to: in a case that roughness of a raw wafer obtained through a wire sawing process within a target wavelength range is greater than or equal to a predetermined roughness threshold, determine an index value for representing a wire sawing capability of a currently-used wire sawing slurry based on a geometric similarity between an abrasive particle in the currently-used wire sawing slurry for the wire sawing process and a regular polyhedron; and in a case that the index value is smaller than or equal to a predetermined performance threshold, generate and send an instruction for replenishing a new wire sawing slurry into an equipment for performing the wire sawing process.

[0090] It should be appreciated that, the implementation of the above steps and the embodiments thereof may refer to the implementation of the corresponding steps in the above-mentioned method and the embodiments thereof, and thus will not be particularly defined herein.

[0091] Optionally, the processor 710 may be implemented through at least one hardware form in Digital Signal Processor (DSP), a Field-Programmable Gate Array (FPGA) and a Programmable Logic Array (PLA). The processor 710 may be integrated with one or more of a Central Processing Unit (CPU), a Graphics Processing Unit (GPU), a Neural-network Processing Unit (NPU) and a baseband chip. The CPU is mainly used to process an operating system, a user interface and an application. The GPU takes charges of rendering and drawing content to be displayed on a touch display screen. The NPU is used to achieve an Artificial Intelligence (AI) function. The baseband chip is used to process wireless communication. It should be appreciated that, the baseband chip may also be not integrated into the processor 710, and instead it is implemented via a separate chip.

[0092] The memory 720 includes a Random Access Memory (RAM), or a Read-Only Memory (ROM). Optionally, the memory 720 includes a non-transitory computer-readable storage medium. The memory 720 is configured to store therein an instruction, a program, a code, a code set or an instruction set. The memory 720 includes a program storage area and a data storage area. The program storage area is configured to store therein instruction for implementing the operating system, an instruction for at least one function (e.g., a touch function, an audio playback function or an image playback function), and an instruction for implementing the above-mentioned method. The data storage area is configured to store therein data created according to the operation of the computing device.

[0093] It should be appreciated that, the structure of the computing device in the drawings shall not be construed as limiting the computing device. The computing device may include more or fewer members, or some members may be combined, or the members may be arranged in different modes. For example, the computing device

further includes a display screen, a camera assembly, a microphone, a loudspeaker, a radio frequency circuit, an input unit, a sensor (e.g., accelerometer, an angular velocity sensor or a light sensor), an audio circuit, a Wireless Fidelity (WiFi) module, a power source, and a Bluetooth module, which will not be particularly defined herein.

[0094] The present disclosure further provides in some embodiments a computer-readable storage medium storing therein at least one instruction. The at least one instruction is executed by a processor to implement the above-mentioned method.

[0095] The present disclosure further provides in some embodiments a computer program product including a computer instruction. The computer instruction is stored in a computer-readable storage medium. A processor of a computing device reads the computer instruction from the computer-readable storage medium, and executes the computer instruction to implement the above-mentioned method.

[0096] The present disclosure further provides in some embodiments a wafer obtained using the above-mentioned method. Roughness of the wafer within a target wavelength range includes at least one of: in a case that the target wavelength range is 0 to 1.8 μm , the roughness is 0.01 nm to 1 nm; in a case that the target wavelength range is 1.8 μm to 22 μm , the roughness is 1 nm to 3 nm; and in a case that the target wavelength range is 22 μm to 20 mm, the roughness is 3 nm to 30 nm.

[0097] It should be appreciated that, the functions described in the above embodiment or embodiments may be achieved through hardware, software, firmware or a combination thereof. In a case that the functions are achieved through software, these functions are stored in a computer-readable storage medium or transmitted as one or more instructions or codes on the computer-readable storage medium. The computer-readable medium may include a computer-readable storage medium and a communication medium. The communication medium may include any medium capable of transmitting a computer program from one place to another place. The storage medium may include any available medium capable of being accessed by a general-purpose or dedicated computer.

[0098] The above are merely the preferred embodiments of the present disclosure, but shall not be construed as limiting the scope of the present disclosure. Any person skilled in the art may make modifications and substitutions without departing from the spirit of the present disclosure, and these modifications and substitutions shall also fall within the scope of the present disclosure. Hence, the scope of the present disclosure shall be subject to the scope defined by the appended claims.

What is claimed is:

1. A method for improving roughness of a wafer, comprising:

in a case that roughness of a raw wafer obtained through a wire sawing process within a target wavelength range is greater than or equal to a predetermined roughness threshold, determining an index value for representing a wire sawing capability of a currently-used wire sawing slurry based on a geometric similarity between an abrasive particle in the currently-used wire sawing slurry for the wire sawing process and a regular polyhedron; and

in a case that the index value is smaller than or equal to a predetermined performance threshold, replenishing a new wire sawing slurry into an equipment for performing the wire sawing process.

2. The method according to claim 1, further comprising:

scanning the currently-used wire sawing slurry through a scanning electron microscope, to collect microscopic images of a plurality of abrasive particles in the currently-used wire sawing slurry;

performing image analysis on the collected microscopic image of each abrasive particle, to obtain a length of each side and the quantity of solid angles of each abrasive particle; and

determining the geometric similarity between each abrasive particle and the regular polyhedron based on the length of each side and the quantity of solid angles of each abrasive particle.

3. The method according to claim 2, wherein the determining the geometric similarity between each abrasive particle and the regular polyhedron based on the length of each side and the quantity of solid angles of each abrasive particle comprises:

calculating the geometric similarity between each abrasive particle and the regular polyhedron based on a difference between the quantity of solid angles of each abrasive particle and a variance of the lengths of all the sides.

4. The method according to claim 2, further comprising:

performing image analysis on the collected microscopic image of each abrasive particle, to obtain a maximum diagonal length of each abrasive particle,

wherein the determining an index value for representing a wire sawing capability of a currently-used wire sawing slurry based on a geometric similarity between an abrasive particle in the currently-used wire sawing slurry for the wire sawing process and a regular polyhedron comprises:

obtaining a median of the geometric similarities between all the abrasive particles and the regular polyhedron;

obtaining a variance of the maximum diagonal lengths of all the abrasive particles; and

obtaining the index value for representing the wire sawing capability of the currently-used wire sawing slurry based on the median of the geometric similarities between all the abrasive particles and the regular polyhedron and the variance of the maximum diagonal lengths of all the abrasive particles.

5. The method according to claim 4, wherein the obtaining the index value for representing the wire sawing capability of the currently-used wire sawing slurry based on the median of the geometric similarities between all the abrasive particles and the regular polyhedron and the variance of the maximum diagonal lengths of all the abrasive particles comprises:

calculating the index value for representing the wire sawing capability of the currently-used wire sawing slurry based on a ratio of the median of the geometric similarities between all the abrasive particles and the regular polyhedron to the variance of the maximum diagonal lengths of all the abrasive particles.

6. The method according to claim 1, further comprising:

for each sampling point on a surface of the raw wafer, obtaining original measurement data about a height of the surface of the raw wafer at the sampling point through single-point measurement;

obtaining a wave signal at each sampling point within the target wavelength range using a filter corresponding to the target wavelength range based on the original measurement data at all the sampling points on the surface of the raw wafer; and

determining the roughness of the raw wafer within the target wavelength range based on statistics of amplitudes of the wave signals at all the sampling points within the target wavelength range.

7. The method according to claim 6, wherein the filter is a circular filter and comprises double Gaussian filter functions;

a radius of an operating range of the filter is determined based on a distance between the sampling point and a center of the raw wafer, and in a case that the distance between the sampling point and the center of the raw wafer is smaller than or equal to a critical distance, the radius of the operating range of the filter is a first radius; in a case that the distance between the sampling point and the center of the raw wafer is greater than the critical distance, the radius of the operating range of the filter is a second radius; and the first radius and the second radius are determined based on an upper limit of the target wavelength range, and the first radius is greater than the second radius.

8. The method according to claim 6, wherein the determining the roughness of the raw wafer within the target wavelength range based on the statistics of the amplitudes of the wave signals at all the sampling points within the target wavelength range comprises:

dividing the raw wafer into a plurality of to-be-analyzed regions;

calculating a range of the amplitudes of the wave signals within the target wavelength range in each to-be-analyzed region based on the amplitudes of the wave

signals within the target wavelength range at the sampling points in each to-be-analyzed region; and

calculating the roughness of the raw wafer within the target wavelength range based on the ranges of the amplitudes of the wave signals within the target wavelength range in all the to-be-analyzed regions.

9. The method according to any one of claims 1 to 8, wherein the target wavelength range comprises at least one of 0 to 1.8 μm , 1.8 μm to 22 μm , and 22 μm to 20 mm.

10. An apparatus for improving roughness of a wafer, comprising a determination member, a comparison member, and a process improvement member, wherein

the determination member is configured to, in a case that roughness of a raw wafer obtained through a wire sawing process within a target wavelength range is greater than or equal to a predetermined roughness threshold, determine an index value for representing a wire sawing capability of a currently-used wire sawing slurry based on a geometric similarity between an abrasive particle in the currently-used wire sawing slurry for the wire sawing process and a regular polyhedron;

the comparison member is configured to compare the index value with a predetermined performance threshold, and in a case that the index value is smaller than or equal to the predetermined performance threshold, trigger the process improvement member; and

the process improvement member is configured to replenish a new wire sawing slurry into an equipment for performing the wire sawing process.

11. A computing device, comprising a processor and a memory, wherein the processor is configured to execute an instruction stored in the memory to implement the method according to any one of claims 1 to 9.

12. A computer-readable storage medium storing therein at least one instruction, wherein the at least one instruction is executed by a processor to implement the method according to any one of claims 1 to 9.

13. A wafer obtained through a wire sawing process improved using the method according to any one of claims 1 to 9, wherein roughness of the wafer within a target wavelength range comprises at least one of:

in a case that the target wavelength range is 0 to 1.8 μm , the roughness is 0.01 nm to 1 nm;

in a case that the target wavelength range is 1.8 μm to 22 μm , the roughness is 1 nm to 3 nm; and

in a case that the target wavelength range is 22 μm to 20 mm, the roughness is 3 nm to 30 nm.