

WAFER, WAFER SURFACE NANO-TOPOGRAPHY PREDICTION METHOD, APPARATUS, DEVICE AND MEDIUM

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims a priority of the Chinese patent application No. 202410895811.6 filed on July 5, 2024, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure relates to the field of semiconductor manufacturing, in particular to a wafer, a wafer surface nano-topography prediction method, apparatus, device and 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 manufacturing processes as wire sawing, lapping, etching, grinding and Chemical Mechanical Polishing (CMP) 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 nano-topography (NT) is an important quality parameter in the surface topography parameters of the wafer.

[0004] In a conventional scheme, the NT detection is typically performed on the wafer after a last surface manufacturing process, i.e., the CMP. However, the NT, as a quality parameter related to short-wave characteristics, is significantly influenced by the manufacturing process before the CMP, i.e., during the implementation of the conventional scheme, problems occurring in the manufacturing process before the CMP may merely be discovered after the CMP. Therefore, the wafer that encounters issues prior to the CMP is still subjected to the complete manufacturing process, resulting in a waste of production resources.

SUMMARY

[0005] Based on the above, the present disclosure intends to provide a wafer, a wafer surface nano-topography prediction method, apparatus, device and medium, so as to predict a predicted nano-topography value of the wafer after a follow-up process based on a measured nano-topography value of the wafer obtained after a current manufacturing process, and monitor product performance in a front-end manufacturing process based on the nano-topography data obtained through prediction, thereby to prevent defective wafers obtained through the front-end manufacturing process from entering the follow-up manufacturing process, and prevent a waste of production resources.

[0006] The technical solution of the present disclosure is implemented as follows.

[0007] In a first aspect, the present disclosure provides in some embodiments a wafer surface nano-topography prediction method, including: performing filtration and data processing on obtained surface topography measurement data of the wafer using a stepwise-designed filter in a process of manufacturing the wafer, to obtain a measured nano-topography value nt of the wafer; and predicting a predicted nano-topography value NT of the wafer after a follow-up manufacturing process based on a prediction function $f(nt) = NT$ and the measured nano-topography value nt of the wafer.

[0008] In a second aspect, the present disclosure provides in some embodiments a wafer surface nano-topography prediction apparatus, including a filtering member and a prediction member. The filtering member is configured to perform filtration and data processing on obtained surface topography measurement data of the wafer using a stepwise-designed filter in a process of manufacturing the wafer, to obtain a measured nano-topography value nt of the wafer; and the prediction member is configured to predict a predicted nano-topography value NT of the wafer after a follow-up manufacturing process based on a prediction function $f(nt) = NT$ and the measured nano-topography value nt of the wafer.

[0009] 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 prediction method in the first aspect.

[0010] 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 prediction method in the first aspect.

[0011] In a fifth aspect, the present disclosure provides in some embodiments a wafer. In a case that a predicted nano-topography value NT of the wafer is smaller than 5 nm at a size of 2 mm*2 mm and/or smaller than 10 nm at a size of 10 mm*10 mm, a nano-topography value of the finally-obtained wafer is smaller than 5 nm at a size of 2 mm*2 mm and smaller than 10 nm at a size of 10 mm*10 mm.

[0012] According to the wafer, the wafer surface nano-topography prediction method, apparatus, device and medium in the embodiments of the present disclosure, the predicted nano-topography value of the wafer after the follow-up process is predicted based on the prediction function and the measured nano-topography value of the wafer obtained after a current manufacturing process. Based on the predicted nano-topography value, it is able to not only monitor each manufacturing process to ensure stability and uniformity of a manufacturing device adopted by the manufacturing process, but also monitor a product of each manufacturing process to ensure that a qualified product enters a next manufacturing process, improve microscopic topography quality of a surface of the wafer, and prevent the manufacture of unqualified products in the follow-up manufacturing process, thereby to reduce the manufacture cost. In addition, it is able to determine whether there is a problem for a process which has already been completed, thereby to help to adjust the process.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Fig. 1 is a flow chart of a wafer surface nano-topography prediction method according to an embodiment of the present disclosure;

[0014] Fig. 2 is a schematic view showing linear correlation between predicted NT values and actual NT values obtained based on sampling data about 100 wafers according to an embodiment of the present disclosure;

[0015] Fig. 3 is a schematic view showing a wafer surface nano-topography prediction apparatus according to an embodiment of the present disclosure;

[0016] Fig. 4 is another schematic view showing a wafer surface nano-topography prediction apparatus according to an embodiment of the present disclosure; and

[0017] Fig. 5 is a schematic view showing a computing device according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0018] The technical solution in the embodiments of the present disclosure will be described hereinafter in a clear and complete manner in conjunction with the drawings.

[0019] In a conventional scheme, a surface of a wafer obtained after a CMP process is divided into analysis regions based on a predetermined dimension, then PV values in filtered measurement data at each sampling point in each analysis region are ranked in an ascending order, and then the PV value at a corresponding position is selected based on a predetermined percentage (e.g., 99.5%) as a nano-topography (NT) value of the wafer.

[0020] On the surface of the wafer, the filtered measurement data at the sampling points in each region fluctuates, and this fluctuation is caused by the superimposition of wave signals at different wavelengths from the perspective of wave. Different wavelengths correspond to different sizes of the regions where the fluctuation occurs, i.e., the smaller the wavelength of the wave signal, the smaller the size of the region represented by the wave signal where fluctuation in the measurement data occurs; and

the larger the wavelength of the wave signal, the larger the size of the region represented by the wave signal where the fluctuation in the measurement data occurs. In the fluctuation in the measurement data, signal data with a large wavelength includes such parameters as bow and warp, and these parameters are approximately constant after a wire sawing process and are less affected by a follow-up manufacturing process. For signal data with a short wavelength, e.g., nano-topography value, it is affected by all front-end processing stages before the CMP process. The NT value of the wafer obtained in the conventional scheme is an NT value after the CMP process, and it merely indicates the performance of the entire wafer manufacturing procedure, but it cannot be used to evaluate the performance of each manufacturing process. In addition, along with an increasing demand on the microscopic surface topography of the wafer in an advanced manufacturing process, each manufacturing process needs to be monitored, so as to ensure the stability and uniformity of manufacturing devices adopted in the processing stages, monitor a product in each manufacturing process, and ensure that a qualified product enters a next manufacturing process, thereby to improve the microscopic topography quality of the surface of the wafer.

[0021] Based on the above, the present disclosure provides in some embodiments a wafer surface nano-topography prediction method, which includes Steps S101 and S102.

[0022] Step S101: performing filtration and data processing on obtained surface topography measurement data of the wafer using a stepwise-designed filter in a process of manufacturing the wafer, to obtain a measured nano-topography value *nt* of the wafer.

[0023] In the embodiments of the present disclosure, the measured nano-topography value of the wafer is obtained after any process in a wafer manufacturing procedure. In some illustrative embodiments of the present disclosure, after any manufacturing process (e.g., wire sawing), a surface height of a sampling point on the surface of the wafer obtained after the wire sawing is measured using a single-point measurement scheme, so as to obtain the surface topography measurement data of the wafer.

[0024] In the above, the single-point measurement scheme is just a scheme in which the measurement data about merely one sampling point is measured in a single measurement procedure. For example, a contact-type measurement scheme is adopted, e.g., a probe is in contact with the surface of the wafer and moves horizontally along the surface of the wafer. During the horizontal movement, longitudinal displacement occurs for the probe due to a height difference of the surface of the to-be-measured wafer. The longitudinal displacement is detected by a displacement sensor and converted into height data about the surface of the to-be-measured wafer, i.e., historical measurement data about a height of a surface of a historical wafer. For example, a non-contact-type measurement scheme, e.g., capacitive measurement or laser focusing measurement, may also be adopted.

[0025] Of course, in some illustrative embodiments of the present disclosure, the surface topography measurement data of the wafer after the current manufacturing process is obtained merely through a single measurement procedure, e.g., an optical measurement scheme (e.g., Fizeau interference or differential interference) is adopted, which will not be particularly defined herein.

[0026] To be specific, a sampling spacing adopted in the measurement is determined based on precision of a device for measurement and a specific formula. For example, for an optical measurement device, the sampling spacing is as low as 0.2 mm, and for some capacitive measurement devices having low precision, the sampling spacing is 4 mm.

[0027] In the embodiments of the present disclosure, the surface topography measurement data at all sampling points is considered as a three-dimensional fluctuation from the entire surface of the wafer. This fluctuation is obtained through the superimposition of wave signals having different wavelengths. For the NT value, a corresponding wavelength range is 22 μm to 20 mm. In some illustrative embodiments of the present disclosure, the surface topography measurement data is filtered by a filter to obtain filter values within the range of 22 μm to 20 mm.

[0028] In some illustrative embodiments of the present disclosure, the surface topography measurement data at all the sampling points on the surface of the wafer is not filtered using a filter with a constant size. The size of the filter changes along with the positions of the sampling points. For example, the filter is a stepwise-designed filter, and a size of the stepwise-designed filter is designed based on a target wavelength range, the sampling spacing and a sampling point position for the surface topography measurement data of the wafer.

[0029] In the embodiments of the present disclosure, taking the target wavelength range of 22 μm to 20 mm as an example, after obtaining the filter values within the range of 22 μm to 20 mm, the surface of the wafer is divided into a plurality of to-be-analyzed regions, and a PV value about the filter value in each to-be-analyzed region is obtained, the PV values for all the to-be-analyzed regions are ranked in an ascending order, and then some PV values are selected based on a predetermined percentage as the measured nano-topography value of the wafer after the wire sawing.

[0030] Step S102: predicting a predicted nano-topography value NT of the wafer after a follow-up manufacturing process based on a prediction function $f(nt) = NT$ and the measured nano-topography value nt of the wafer.

[0031] In the embodiments of the present disclosure, the follow-up manufacturing process refers to a manufacturing process in the wafer manufacturing procedure after the process for obtaining the surface topography measurement data of the wafer in Step S101. For example, in a case that the surface topography measurement data of the wafer after the wire sawing process is obtained in Step S101, the follow-up manufacturing process in Step S102 is a process in the wafer manufacturing procedure after the wire sawing process, e.g., a grinding process, an etching process, a milling process or a CMP process.

[0032] Taking the wire sawing process as an example, in a case that a manufacturing procedure after the wire sawing process forms normal distribution of the NT values of the wafer, it may be considered that there is a constant functional relationship between the nano-topography value of the wafer after the wire sawing

process and the nano-topography value of the wafer after the follow-up manufacturing process, i.e., $NT = f(nt)$, where NT represents the predicted nano-topography value of the wafer after the follow-up manufacturing process, nt represents the measured nanotopograpy value of the wafer obtained in Step S101, and $f()$ represents the prediction function.

[0033] In the embodiments of the present disclosure, after obtaining the predicted nano-topography value of the wafer, it is able to evaluate the manufacturing process which has been completed currently.

[0034] In some illustrative embodiments of the present disclosure, an operating stage of a device for the manufacturing process which has been completed currently is determined based on statistics of the predicted nano-topography values of the wafer, so as to ensure the stability and uniformity of the device, and prevent the occurrence of a mechanical error. For example, the predicted NT values of all the products manufactured by each device every day are monitored, and in a case that the predicted NT values are discrete, there are too many discrete values and an average value is too large, it means that the device is unstable and needs to be stopped for maintenance.

[0035] In some illustrative embodiments of the present disclosure, whether the follow-up manufacturing process is to be performed is determined based on a comparison between the predicted nano-topography value of the wafer and a predetermined evaluation index, so as to select the qualified products, and prevent the occurrence of unqualified products obtained through the follow-up manufacturing process, thereby to reduce the manufacturing cost.

[0036] In some illustrative embodiments of the present disclosure, a process parameter of the manufacturing process which has been completed currently is adjusted based on the predicted nano-topography value of the wafer. For example, whether a process which has been completed has a problem is determined based on the predicted nano-topography value of a product obtained through each manufacturing process, so as to help to adjust the process in a targeted manner. In addition, during the process

adjustment, a process parameter of the manufacturing process may also be returned and adjusted based on the predicted nano-topography value.

[0037] Through the technical solution in Fig. 1, the predicted nano-topography value of the wafer after the follow-up process is predicted based on the prediction function and the measured nano-topography value of the wafer obtained after the current manufacturing process. Based on the predicted nano-topography value, it is able to not only monitor each manufacturing process to ensure stability and uniformity of a manufacturing device adopted by the manufacturing process, but also monitor a product of each manufacturing process to ensure that a qualified product enters a next manufacturing process, improve microscopic topography quality of the surface of the wafer, and prevent the manufacture of unqualified products in the follow-up manufacturing process, thereby to reduce the manufacture cost. In addition, it is able to determine whether there is a problem for a process which has already been completed, thereby to help to adjust the process.

[0038] For the technical solution in Fig. 1, in some possible embodiments of the present disclosure, a size of the stepwise-designed filter in Step S101 is designed based on the target wavelength range, the sampling spacing and the sampling point position for the surface topography measurement data of the wafer. A specific design procedure includes: determining a filter using bivariate gaussian low-pass filter functions based on the target wavelength range; determining a filter critical dimension based on an upper wavelength bound of the target wavelength range; performing edge contraction based on the sampling point position; and in a case that a distance between the sampling point position and a center of a surface of the wafer is smaller than or equal to the filter critical dimension, determining a radius of the stepwise-designed filter as a first radius; or in a case that the distance between the sampling point position and the center of the surface of the wafer is greater than the filter critical dimension, determining the radius of the stepwise-designed filter as a second radius. The first radius is greater than the second radius.

[0039] In the above, the target wavelength range is 22 μm to 20 mm corresponding to the NT value. In the embodiments of the present disclosure, the filter is a circular filter, and it consists of bivariate gaussian low-pass filter functions. To be specific, the determining the filter using the bivariate gaussian low-pass filter functions based on the target wavelength range includes: determining a first Gaussian low-pass filter function in which a low-pass filter range covers the upper bound of the target wavelength range; determining a second Gaussian low-pass filter function in which a low-pass filter range covers a lower bound of the target wavelength range; and obtaining a function G_{DHP} for describing the filter based on the first Gaussian low-pass filter function G_{LP1} and the second Gaussian low-pass filter function G_{LP2} through a formula $G_{\text{DHP}} = G_{\text{LP1}} (1 - G_{\text{LP2}})$.

[0040] For example, a relationship between a cutoff wavelength and a standard deviation is defined as $\lambda_c = 6\sigma$, and the Gaussian low-pass filter functions are both $\exp\left(-\left(\frac{\lambda}{\sqrt{2}\sigma}\right)^2\right)$, where λ represents the wavelength. It should be appreciated that, for the first Gaussian low-pass filter function and the second Gaussian low-pass filter function, the standard deviations σ are different, so as to reserve signals within different wavelength ranges.

[0041] After obtaining the circular filter through the above-mentioned specific scheme, an operating range of the filter needs to be set based on the sampling point position for the filtration calculation. To be specific, 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 and effectively obtain surface topography features at different scales, 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 edge

contraction. In the embodiments of the present disclosure, the edge contraction is stepwise, i.e., a filter critical dimension 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. As compared with a situation where the sampling point is close to the center of the surface of the wafer, in a case that the sampling point is close to the edge of the surface of the wafer, the operating range of the filter should be contracted (an edge processing coefficient is k during the contraction), and in a case that the distance between the sampling point and the center of the surface of the wafer is greater than the filter critical dimension, the second radius has a constant value smaller than the first radius. Taking a 12-inch wafer as an example, its radius R is 150 mm. During the measurement, an Exclude Edge (EE) is usually 3mm, and an upper bound w of the target wavelength range is 20 mm, so the filter critical dimension a is calculated through $a=R-EE-0.5*w$.

[0042] In the embodiments of the present disclosure, Table 1 shows the stepwise radiuses of the filter determined based on the filter critical dimension.

Position of sampling point	Stepwise radiuses
0	$0.5*w$
...	$0.5*w$
a	$0.5*w$
$a+m$	$k*w(k=0.2)$
$a+2m$	$k*w(k=0.2)$
...	$k*w(k=0.2)$
R	$k*w(k=0.2)$

Table 1

[0043] In some illustrative embodiments of the present disclosure, in a case that the distance between the sampling point and the center of the surface of the wafer, the second radius, apart from being smaller than the first radius, may also decrease, e.g.,

linearly decrease, along with an increase in the distance between the sampling point and the center of the surface of the wafer, i.e., it may not be a constant value.

[0044] Based on the above, after obtaining the circular filter and the radius of the operating range, the surface topography measurement data of the wafer is filtered using the filter, so as to obtain the measured nano-topography value of the wafer. To be specific, the obtaining the measured nano-topography value of the wafer includes: after filtering the surface topography measurement data of the wafer using the stepwise-designed filter, obtaining a filter value at each sampling point position; dividing all sampling points into at least one to-be-analyzed region based on a predetermined dimension; obtaining a PV value of each to-be-analyzed region based on a maximum filter value and a minimum filter value in the to-be-analyzed region; and ranking the PV values of all the to-be-analyzed regions in an ascending order, and selecting the PV value based on a predetermined percentage as the measured nano-topography value of the wafer.

[0045] In the above, in a case that the sampling point is in the vicinity of the edge of surface of the wafer and the operating range of the filter extends the edge of the surface of the wafer, during the filtration, data may be filled through interpolation or may not be filled with respect to part of the operating range of the filter which extends beyond the edge of the surface of the wafer. The interpolation includes linear extrapolation, symmetric interpolation, or cubic spline interpolation, which will not be particularly defined herein.

[0046] In the above, the division of the to-be-analyzed region may be determined based on specific requirements on the surface topography measurement and the analysis. In the embodiments of the present disclosure, the to-be-analyzed regions are obtained through uniformly dividing the surface of the wafer into several small grids, each grid serves as one to-be-analyzed region, and each grid is a square having a size of $10\ \mu\text{m} \times 10\ \mu\text{m}$, or a size of $20\ \mu\text{m} \times 20\ \mu\text{m}$.

[0047] In the above, after the PV values in each to-be-analyzed region are ranked in an ascending order, and an N^{th} PV value from the bottom is selected based on the

predetermined percentage, e.g., 99% or 99.5%, as the measured nano-topography value of the wafer.

[0048] For the technical solution in Fig. 1, in some possible embodiment of the present disclosure, the method further includes a step for obtaining the prediction function. To be specific, this step includes: performing mathematical modeling and fitting based on a measured nano-topography value of a historical wafer after a current manufacturing process and a measured nano-topography value of the historical wafer after the follow-up manufacturing process, and obtaining the prediction function through linear fitting or polynomial fitting.

[0049] To be specific, regardless of the measured nano-topography value after the current manufacturing process or the measured nano-topography value after the follow-up manufacturing process, the filtration and data processing are performed on the surface topography measurement data of the historical wafer using the stepwise-designed filter, so as to obtain the measured nano-topography value of the historical wafer. During the implementation, a specific procedure of obtaining the measured nano-topography value of the historical wafer is the same as the above-mentioned procedure of obtaining the measured nano-topography value of the wafer, and thus will not be particularly defined herein.

[0050] In some illustrative embodiments of the present disclosure, the obtaining the prediction function through linear fitting or polynomial fitting specifically includes the following steps.

[0051] At first, a data set is obtained based on the measured nano-topography value of the historical wafer after the current manufacturing process and the nano-topography value of the historical wafer after the follow-up manufacturing process. For example, the data set is stored in the form of matrix, and each row in the matrix corresponds to one sample.

[0052] Next, an appropriate prediction function $f(nt) = NT$ is selected according to the practical need, e.g., a linear function, a polynomial function, an exponential function, or logarithmic function. Taking the polynomial fitting as an

example, usually a least square method is used for the fitting, i.e., parameters of the prediction function $f(nt)$ are determined through minimizing a residual sum of squares between an actually-observed NT value and a fitted value (a value of $f(nt)$), so as to finally obtain the prediction function or the actual production.

[0053] Based on the above, a specific embodiment is provided hereinafter for illustration. In this embodiment, 100 raw wafers each having a radius of 150 mm obtained through wire sawing are taken as examples. A part of an edge of each raw wafer is removed at an EE of 4 mm, and then height data about a surface of the wafer is sampled through capacitive measurement, so as to obtain the surface topography measurement data of the raw wafer. For example, the height data is sampled evenly using a polar coordinate system with a center of the surface of the wafer as a pole, i.e., the sampling points along a diameter direction are measured every 45° , and a sampling spacing in the diameter direction is 4 mm. In the polar coordinate system, the surface topography measurement data about $8*37$ sampling points is obtained. From the perspective of the entire surface of the wafer, each sampling point may be considered as a pixel point.

[0054] Next, the surface topography measurement data about each sampling point is filtered using the above-mentioned filter, and filter values of all the sampling points are divided into to-be-analyzed regions at a size of 10 mm*10 mm. For each to-be-analyzed region, a PV value is determined based on the filter value of each pixel point (sampling point). The PV values for all the to-be-analyzed regions are ranked in an ascending order, and an N^{th} PV value from the bottom is selected based on a predetermined percentage, e.g., 99% or 99.5%, as the measured nano-topography value of the raw wafer after the wire sawing.

[0055] Then, predicted nano-topography values of the 100 raw wafers are calculated using a fitting function based on the measured nano-topography values of the 100 raw wafers obtained after wire sawing. In the embodiments of the present disclosure, the fitting function is obtained through linearly fitting data about the historical wafers, as indicated by a dotted line in Fig. 2. In the embodiments of the

present disclosure, the prediction function is $NT=1.9785*nt+5.9023$, where nt represents the measured nano-topography value after the wire sawing, and NT represents the predicted nano-topography value.

[0056] Finally, in a case that the follow-up manufacturing process is a CMP process, whether there is correlation between actual nano-topography value of each of the 100 raw wafers after the CMP process and the predicted nano-topography value is analyzed. With reference to Fig. 2 again, the predicted nano-topography value after the wire sawing and the actual nano-topography value after the CMP process are taken as coordinates, and the predicted nano-topography values and the actual nano-topography values of the 100 raw wafers are indicated by points in Fig. 2. In order to validate whether there is the correlation between the predicted nano-topography value (predicted NT value) and the actual nano-topography value (actual NT value), a residual between a fitted curve and actual data, or a value of R^2 of the fitted curve, is calculated based on the predicted NT value and the actual NT value. Table 2 shows the correlation between the predicted NT value and the actual NT value for the 100 wafers.

Data volume	~100pcs
predicted NT-actual NT) R^2	0.485

Table 2

[0057] As shown in Table 2, there is the correlation between the predicted NT value and the actual NT value.

[0058] Based on the above-mentioned wafer surface nano-topography prediction method, in a case that the predicted nano-topography value of the wafer is smaller than 5 nm at a size of 2 mm*2 mm and/or smaller than 10 nm at a size of 10 mm*10 mm, the nano-topography value of the wafer is smaller than 5 nm at a size of 2 mm*2 mm and smaller than 10 nm at a size of 10 mm*10 mm.

[0059] It should be appreciated that, the manufacturing process where the predicted nano-topography value is obtained is arranged before the manufacturing process where the nano-topography value of the wafer is obtained. For example, the predicted nano-topography value is obtained after the wire sawing process, and the

nano-topography value of the wafer is obtained after the CMP process. Alternatively, the predicted nano-topography value is obtained after the CMP process, and the nano-topography value of the wafer is obtained in a case that the wafer enters a back-end semiconductor manufacture process, which will not be particularly defined herein.

[0060] Based on a same inventive concept as the above-mentioned technical solution, as shown in Fig. 3, the present disclosure provides in some embodiments a wafer surface nano-topography prediction apparatus 300, which includes a filtering member 301 and a prediction member 302. The filtering member 301 is configured to perform filtration and data processing on obtained surface topography measurement data of the wafer using a stepwise-designed filter in a process of manufacturing the wafer, to obtain a measured nano-topography value nt of the wafer; and the prediction member 302 is configured to predict a predicted nano-topography value NT of the wafer after a follow-up manufacturing process based on a prediction function $f(nt) = NT$ and the measured nano-topography value nt of the wafer.

[0061] In some illustrative embodiments of the present disclosure, a size of the stepwise-designed filter is designed based on a target wavelength range, a sampling spacing and a sampling point position for the surface topography measurement data of the wafer. Correspondingly, the filtering member 301 is configured to: determine a filter using bivariate gaussian low-pass filter functions based on the target wavelength range; determine a filter critical dimension based on an upper wavelength bound of the target wavelength range; perform edge contraction based on the sampling point position; and in a case that a distance between the sampling point position and a center of a surface of the wafer is smaller than or equal to the filter critical dimension, determine a radius of the stepwise-designed filter as a first radius; or in a case that the distance between the sampling point position and the center of the surface of the wafer is greater than the filter critical dimension, determine the radius of the stepwise-designed filter as a second radius, wherein the first radius is greater than the second radius.

[0062] In some illustrative embodiments of the present disclosure, the filtering member 301 is configured to: determine a first Gaussian low-pass filter function in

which a low-pass filter range covers the upper bound of the target wavelength range; determine a second Gaussian low-pass filter function in which a low-pass filter range covers a lower bound of the target wavelength range; and obtain a function G_{DHP} for describing the filter based on the first Gaussian low-pass filter function G_{LP1} and the second Gaussian low-pass filter function G_{LP2} through a formula $G_{DHP} = G_{LP1} (1 - G_{LP2})$.

[0063] In some illustrative embodiments of the present disclosure, the filtering member 301 is configured to: after filter the surface topography measurement data of the wafer using the stepwise-designed filter, obtaining a filter value at each sampling point position; divide all sampling points into at least one to-be-analyzed region based on a predetermined dimension; obtain a PV value of each to-be-analyzed region based on a maximum filter value and a minimum filter value in the to-be-analyzed region; and rank the PV values of all the to-be-analyzed regions in an ascending order, and select the PV value based on a predetermined percentage as the measured nano-topography value of the wafer.

[0064] Referring to Fig. 4, the prediction apparatus 30 further includes a fitting member 303. The fitting member 303 is configured to perform mathematical modeling and fitting based on a measured nano-topography value of a historical wafer after a current manufacturing process and a measured nano-topography value of the historical wafer after the follow-up manufacturing process, and obtain the prediction function through linear fitting or polynomial fitting.

[0065] In some illustrative embodiments of the present disclosure, the filtering member 301 is further configured to perform filtration and data processing on surface topography measurement data of the historical wafer using the stepwise-designed filter, to obtain the measured nano-topography value of the historical wafer.

[0066] In some illustrative embodiments of the present disclosure, the prediction apparatus 30 further includes a feedback member 304. The feedback member 303 is configured to: determine an operating stage of a device for a front-end manufacturing process which has been completed currently based on statistics of the predicted nano-topography value of the wafer; or determine whether a follow-up manufacturing

process is to be performed based on a comparison result between the predicted nano-topography value of the wafer and a predetermined evaluation index; or adjust a process parameter of a manufacturing process which has been completed currently based on the predicted nano-topography value of the wafer.

[0067] It should be appreciated that, the implementation of the function of each member in the prediction apparatus may refer to that of the corresponding step in the prediction method and examples thereof, and thus will not be particularly defined herein.

[0068] Fig. 5 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 50 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 50 has a communication function, and it may access a wired network or a wireless network. The computing device 50 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 50 receives data based on the wired network or the wireless network. It should be appreciated that, the computing device 50 is used to perform calculation and processing in the technical solution of the present disclosure, which will not be particularly defined herein.

[0069] As shown in Fig. 5, the computing device includes one or more of a processor 510 and a memory 520.

[0070] Optionally, the processor 510 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 520, and calling data stored in the memory 520. Optionally, the processor 510 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 510 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 510, and instead it is implemented via a separate chip.

[0071] The memory 520 includes a Random Access Memory (RAM), or a Read-Only Memory (ROM). Optionally, the memory 520 includes a non-transitory computer-readable storage medium. The memory 520 is configured to store therein an instruction, a program, a code, a code set or an instruction set. The memory 520 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.

[0072] 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.

[0073] 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 prediction method.

[0074] 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 prediction method.

[0075] The present disclosure further provides in some embodiments a wafer. In a case that a predicted nano-topography value NT of the wafer obtained through the above-mentioned predication method is smaller than 5 nm at a size of 2 mm*2 mm and/or smaller than 10 nm at a size of 10 mm*10 mm, a finally-obtained nano-topography value of the wafer is smaller than 5 nm at a size of 2 mm*2 mm and smaller than 10 nm at a size of 10 mm*10 mm.

[0076] 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.

[0077] It should be appreciated that, the technical solutions in the embodiments of the present disclosure may be combined in any way in a case of no conflict.

[0078] 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 wafer surface nano-topography prediction method, comprising:

in a process of manufacturing a wafer, performing filtration and data processing on obtained surface topography measurement data of the wafer using a stepwise-designed filter, to obtain a measured nano-topography value nt of the wafer; and

predicting a predicted nano-topography value NT of the wafer after a follow-up manufacturing process based on a prediction function $f(nt) = NT$ and the measured nano-topography value nt of the wafer.

2. The method according to claim 1, wherein a size of the stepwise-designed filter is designed based on a target wavelength range, a sampling spacing and a sampling point position for the surface topography measurement data of the wafer, wherein the method comprises:

determining a filter using bivariate gaussian low-pass filter functions based on the target wavelength range;

determining a filter critical dimension based on an upper wavelength bound of the target wavelength range;

performing edge contraction based on the sampling point position; and
in a case that a distance between the sampling point position and a center of a surface of the wafer is smaller than or equal to the filter critical dimension, determining a radius of the stepwise-designed filter as a first radius; or, in a case that the distance between the sampling point position and the center of the surface of the wafer is greater than the filter critical dimension, determining the radius of the stepwise-designed filter as a second radius, wherein the first radius is greater than the second radius.

3. The method according to claim 2, wherein the determining a filter using bivariate gaussian low-pass filter functions based on the target wavelength range, comprises:

determining a first Gaussian low-pass filter function in which a low-pass filter range covers the upper bound of the target wavelength range;

determining a second Gaussian low-pass filter function in which a low-pass filter range covers a lower bound of the target wavelength range; and

obtaining a function G_{DHP} for describing the filter based on the first Gaussian low-pass filter function G_{LP1} and the second Gaussian low-pass filter function G_{LP2} through a formula $G_{DHP}=G_{LP1}(1-G_{LP2})$.

4. The method according to claim 2, wherein the performing filtration and data processing on obtained surface topography measurement data of the wafer using a stepwise-designed filter, to obtain a measured nano-topography value nt of the wafer, comprises:

after filtering the surface topography measurement data of the wafer using the stepwise-designed filter, obtaining a filter value at each sampling point position;

dividing all sampling points into at least one to-be-analyzed region based on a predetermined dimension;

obtaining a peak-to-valley (PV) value of each to-be-analyzed region based on a maximum filter value and a minimum filter value in each to-be-analyzed region; and

ranking PV values of all the to-be-analyzed regions in ascending order, and selecting the PV value based on a predetermined percentage as the measured nano-topography value of the wafer.

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

performing mathematical modeling and fitting based on a measured nano-topography value of a historical wafer after a current manufacturing process and a measured nano-topography value of the historical wafer after the follow-up manufacturing process, and obtaining the prediction function through linear fitting or polynomial fitting.

6. The method according to claim 5, further comprising:

performing filtration and data processing on surface topography measurement data of the historical wafer using the stepwise-designed filter, to obtain the measured nano-topography value of the historical wafer.

7. A wafer surface nano-topography prediction apparatus, comprising: a filtering member and a prediction member, wherein

the filtering member is configured to, in a process of manufacturing a wafer, perform filtration and data processing on obtained surface topography measurement data of the wafer using a stepwise-designed filter, to obtain a measured nano-topography value nt of the wafer; and

the prediction member is configured to predict a predicted nano-topography value NT of the wafer after a follow-up manufacturing process based on a prediction function $f(nt) = NT$ and the measured nano-topography value nt of the wafer.

8. 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 6.

9. 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 6.

10. A wafer, wherein in a case that a predicted nano-topography value NT of the wafer is smaller than 5 nm at a size of 2 mm*2 mm and/or smaller than 10 nm at a size of 10 mm*10 mm, a nano-topography value of the wafer is smaller than 5 nm at a size of 2 mm*2 mm and smaller than 10 nm at a size of 10 mm*10 mm.