

METHOD AND APPARATUS FOR REAL-TIME MONITORING OF WAFER WARPAGE

FIELD OF THE INVENTION

The present invention relates to the technical field of semiconductor chip manufacturing, and in particular to a method and an apparatus for real-time monitoring of wafer warpage.

BACKGROUND

During semiconductor chip production, plasma-enhanced chemical vapor deposition (PECVD) is often used to deposit various dielectric layers, metal layers, etc. A manipulator places a wafer on a heating tray in a chamber, and reaction gas enters the chamber through a showerhead directly above the heating tray. Under the effect of radio frequency, plasma is formed, and reactive ions migrate to the wafer surface for reaction, forming silicide and other thin films on the wafer surface.

During the thin film deposition, due to the different thermal expansion coefficients of the newly formed film and the wafer substrate, stress is generated between the film and the wafer substrate, making the wafer warp.

When the thin film stress is large, especially when the thin film is thick, the wafer will warp to a large extent and partially detach from the heating tray, resulting in low heating efficiency, poor film quality uniformity, and even electric arc in severe cases.

Currently, the industry mainly monitors the thin film stress through measuring equipment before and after film formation to control the thin film stress within a certain range, but cannot monitor the wafer deformation during the film formation in real time.

SUMMARY

In view of the above problems, the purpose of the present invention is to provide a method and an apparatus for real-time monitoring of wafer warpage, which can monitor the wafer warpage during film formation in real time.

To achieve the above object, the present invention provides the following technical solution:

A method for real-time monitoring of wafer warpage, comprising: during the thin film deposition on a wafer, monitor the heating power change rate $\Delta P / P_0$ of each heating area on a heating tray in real time, wherein ΔP is the heating power variation of the heating area, P_0 is the heating power of the heating area in the initial state, the heating tray includes at least two heating areas, each heating area is in a set constant temperature control state, the wafer is arranged on the at least two heating areas, and the wafer has a wafer area corresponding to each of the heating areas; and determine whether the corresponding wafer area is detached from the heating tray according to the heating power change rate $\Delta P / P_0$.

The present invention also provides another method for real-time monitoring of wafer warpage, comprising: during the thin film deposition on a wafer, monitor the wafer warpage variation ΔBOW in real time;

if the wafer warpage variation ΔBOW exceeds a preset threshold, determine process conditions that need to be changed according to the mapping relationship between the wafer warpage variation ΔBOW and the process conditions, and process the wafer using the changed process conditions, so that the wafer warpage is controlled within the target warpage range.

The present invention also provides an apparatus for real-time monitoring of wafer warpage, comprising: a memory configured to store at least one mapping relationship, and the mapping relationship is the mapping relationship between the wafer warpage variation ΔBOW and process conditions; a monitor configured to monitor the wafer warpage variation ΔBOW in real time; a controller configured to receive the wafer warpage variation ΔBOW , and if the wafer warpage variation ΔBOW exceeds the preset threshold, determine the process conditions that need to be changed according to the mapping relationship between the wafer warpage variation ΔBOW and the process conditions; an operator configured to receive the changed process conditions and process the wafer using the changed process conditions.

Compared with the prior art, the present invention provides the following

beneficial effects:

By using this invention, the wafer warpage can be monitored in real time during the thin film deposition, that is, the wafer warpage variation ΔBOW can be monitored in real time without the need for an additional measuring equipment.

BRIEF DESCRIPTION OF THE DRAWINGS

To more clearly illustrate embodiments of the present invention or the technical solutions in the prior art, the drawings needed in the description of the embodiments or the prior art will be briefly introduced in the following description. Obviously, the drawings in the following description are only some embodiments of the present invention. For those of ordinary skill in the art, other drawings can be obtained according to these drawings without creative labor.

FIG. 1 shows a flowchart of a method for real-time monitoring of wafer warpage provided in Embodiment 1 of the present invention.

FIG. 2 shows the first schematic diagram of the state where the heating tray heats the wafer provided in Embodiment 1 of the present invention.

FIG. 3 shows the second schematic diagram of the state where the heating tray heats the wafer provided in Embodiment 1 of the present invention.

FIG. 4 shows the third schematic diagram of the state where the heating tray heats the wafer provided in Embodiment 1 of the present invention.

FIG. 5 shows a fitting curve diagram describing the relationship between the heating power changes of the inner heating coil and the outer heating coil and the warpage in Embodiment 1 of the present invention.

FIG. 6 shows a flowchart of a method for real-time monitoring of wafer warpage provided in Embodiment 2 of the present invention.

FIG. 7 shows a schematic diagram of a thin film deposition apparatus provided in Embodiment 2 of the present invention.

FIGS. 8–13 show diagrams describing the relationship between the thin film stress and the process conditions provided in Embodiment 2 of the present invention.

PREFERRED EMBODIMENTS OF THE INVENTION

To more clearly illustrate technical solutions of the embodiments of the present application, the drawings needed in the description of the embodiments will be briefly introduced in the following description. Obviously, the drawings in the following description are only some examples or embodiments of the present application. For those of ordinary skill in the art, the present application can be applied to other similar scenarios according to these drawings without creative labor. Unless clearly indicated or stated otherwise in the context, the same reference numerals in the figures indicate the same structure or operation.

As shown in the present application and the claims, unless the context clearly indicates exceptions, words such as "one," "a/an," and/or "the" apply to both the singular and plural forms. Generally speaking, the terms "comprise" and "include" only suggest that clearly identified steps and elements are included, and these steps and elements do not constitute an exclusive list. The method or device may also include other steps or elements.

Unless otherwise specified, the relative arrangement of components and steps, numerical expressions, and numerical values set forth in these embodiments do not limit the scope of the present application. In addition, it should be understood that for the convenience of description, the sizes of various parts shown in the drawings are not drawn according to actual proportional relationships. Technologies, methods, and devices known to those of ordinary skill in the art may not be discussed in detail, but where appropriate, these technologies, methods, and devices should be regarded as a part of the authorized specification. In all examples shown and discussed herein, any specific value should be interpreted as merely exemplary, not as a limitation. Therefore, other examples of the exemplary embodiments may provide different values. It should be noted that similar reference numerals and letters indicate similar items in the following drawings. Therefore, once an item is defined in one drawing, the item does not need to be further discussed in subsequent drawings.

In the description of the present application, it should be understood that direction words such as "front, rear, upper, lower, left, right," "transverse, vertical, perpendicular, horizontal," and "top, bottom" usually refer to the directions or positional relationships shown in the drawings. These direction words are only for the convenience of describing the present application and simplifying the description. Unless stated otherwise, these direction words do not indicate or imply that the apparatus or element must provide a specific direction or be constructed and operated in a specific direction, so the direction words cannot be understood as limiting the protection scope of the present application; the direction words "inner, outer" refer to the inner and outer relative to the outline of each component itself.

For the convenience of description, spatial relative terms such as "on," "above," "on the surface," "upper," and the like can be used here to describe spatial position relationships between one device or feature and other devices or features, as shown in the drawings. It should be understood that the spatial relative terms are intended to include different directions of the devices in use or operation, in addition to the directions shown in the drawings. For example, if a device in a drawing is turned over, the device described as "above other devices or structures" or "on other devices or structures" will then be positioned as "below other devices or structures" or "under other devices or structures." Thus, the exemplary term "above" can include both the directions of "above" and "below." The device can also be positioned in other ways (rotated 90 degrees or in other directions), and the spatial relative descriptions used here can be interpreted accordingly.

In addition, it should be noted that words such as "first" and "second" used to define components are only for the convenience of distinguishing corresponding components. Unless otherwise stated, the above words have no special meaning, so the words cannot be understood as limiting the protection scope of the present application. In addition, although the terms used in the present application are selected from publicly known and used terms, some terms in the present application may be selected by the applicant according to his or her judgment, and the detailed meanings of the terms are set forth in the relevant part of the description herein. In addition, the present application should be understood through both the actual terms used and the meaning implied by each term.

The technical solution of the present invention will be further described below with reference to the drawings and through specific embodiments.

Embodiment 1

Please refer to FIG. 1. This embodiment provides a method for real-time monitoring of wafer warpage, and the method includes the following steps:

Step S110: during the thin film deposition on a wafer, monitor the heating power change rate $\Delta P / P_0$ of each heating area on a heating tray in real time, where ΔP is the heating power variation of the heating area, P_0 is the heating power of the heating area in the initial state; the heating tray includes at least two heating areas, each heating area is in a set constant temperature control state, the wafer is arranged on the at least two heating areas, and the wafer has a wafer area corresponding to each heating area; and

Step S120: determine whether the corresponding wafer area is detached from the heating tray according to the heating power change rate $\Delta P / P_0$.

The above steps S110 and S120 will be described below with reference to FIGS. 2 to 5. As shown in FIG. 2, during the thin film deposition, the wafer 2 is placed on the heating tray 1, and the heating tray 1 heats the wafer 2. The heating tray 1 includes a central heating area 11 and an edge heating area 12, and the edge heating area 12 is arranged on the outer periphery of the central heating area 11. The heating tray 1 heats the wafer 2 in a dual-zone manner. The edge heating area 12 includes an outer heating coil for heating the part of the wafer on the edge heating area 12, and the central heating area 11 includes an inner heating coil for heating the part of the wafer on the central heating area 11. The edge heating area 12 and the central heating area 11 jointly heat the entire wafer 2. The inner heating coil and the outer heating coil dynamically adjust the heating power to keep each heating area on the heating tray 1 in a set constant temperature control state.

For example, if the temperature of the heating area is lower or higher than the set temperature, the heating power will be increased or reduced through a relay.

During the thin film deposition, when the wafer 2 does not warp, that is, as shown in FIG. 2, the wafer 2 is flat as a whole, the central part of the wafer 2 is in contact with

the central heating area 11, and the edge part of the wafer 2 is in contact with the edge heating area 12.

However, when the wafer 2 warps, some parts of the wafer will be detached from the heating tray 1, that is, not in contact with the heating tray 1. The method for real-time monitoring of the wafer warpage in this embodiment determines the warpage state of the wafer according to the heating power change rate $\Delta P(C) / P_0(C)$ of the central heating area 11 and the heating power change rate $\Delta P(E) / P_0(E)$ of the edge heating area 12. Wherein, $\Delta P(C)$ indicates the heating power variation of the central heating area, $\Delta P(E)$ indicates the heating power variation of the edge heating area, $P_0(C)$ is the heating power of the central heating area in the initial state, and $P_0(E)$ is the heating power of the edge heating area in the initial state.

As shown in FIG. 3, if the contact between the edge part of the wafer 2 and the edge heating area 12 on the heating tray 1 is reduced, in order to maintain the set temperature, the load of the outer heating coil will become lower, the heating power of the edge heating area 12 will become lower, and the heating power of the central heating area 11 will remain unchanged. In this case, $|\Delta P(C) / P_0(C)|$ is smaller than $|\Delta P(E) / P_0(E)|$, and the wafer 2 undergoes an upward bowl-shaped warpage.

As shown in FIG. 4, if the contact between the central part of the wafer 2 and the central heating area 11 on the heating tray 1 is reduced, the load of the inner heating coil will become lower, and the heating power of the central heating area 11 will become lower. In this case, $|\Delta P(C) / P_0(C)|$ is greater than $|\Delta P(E) / P_0(E)|$, and the wafer 2 undergoes a downward inverted bowl-shaped warpage. It should be noted that the variation range of the heating power of a heating coil varies with the warpage of the wafer 2.

In the present application, the BOW value is used to indicate the warpage of the wafer 2. The warpage state of the wafer 2 can be determined by the positive and negative status of the wafer warpage BOW. As shown in FIGS. 3 and 4, assuming that the upper surface of the wafer 2 is the front side and the lower surface is the back side, the warpage state of the wafer 2 includes: the edge of the wafer 2 warps toward the back side and the middle of the wafer is convex, that is, the wafer 2 warps downward, and the wafer warpage BOW is defined as a negative value, as shown in FIG. 4; or the

edge of the wafer 2 warps toward the front side and the middle of the wafer is concave, that is, the wafer 2 warps upward, and the wafer warpage BOW is defined as a positive value, as shown in FIG. 3.

For example, the heating tray 1 is not limited to including two heating areas, and the heating tray 1 may include a plurality of heating areas, with each of the heating areas used to heat the wafer 2.

According to steps S110 and S120, the method disclosed in the present application monitors the heating power change rate $\Delta P / P_0$ of each heating area in real time, and determines whether the part of the wafer 2 corresponding to the heating area is detached from the heating tray 1 according to the heating power change rate $\Delta P / P_0$. For example, judgment is made according to the magnitude of the heating power change rate $\Delta P / P_0$. When the heating power change rate $\Delta P / P_0$ is lower than a certain value, it indicates that the part of the wafer is detached from the heating tray 1.

In some embodiments, if $\Delta P / P_0$ is smaller than 0 for a certain heating area, it indicates that the heating power of the heating area has changed, and thus indicates that the part of the wafer corresponding to the heating area is detached from the heating tray 1.

In the disclosed embodiments of the present application, the warpage state of the wafer 2 is not limited to the above two states. For example, the overall warpage state of the wafer 2 is determined according to the heating power change rates $\Delta P / P_0$ of all heating areas. The warpage state of the wafer 2 can be saddle-shaped or other special shapes.

According to further research, there is a corresponding relationship between the heating power change rates $\Delta P / P_0$ of the heating areas and the wafer warpage variation ΔBOW . The wafer warpage variation ΔBOW is calculated by the corresponding relationships of $\Delta P(C) / P_0(C) = f1'(\Delta BOW)$ and $\Delta P(E) / P_0(E) = f2'(\Delta BOW)$, wherein $f1'$ indicates the relationship between $\Delta P(C) / P_0(C)$ and ΔBOW , and $f2'$ indicates the relationship between $\Delta P(E) / P_0(E)$ and ΔBOW . $f1'$ and $f2'$ can be a kind of function, such as a linear function, a quadratic function, etc., which is not limited in the present application. If ΔBOW exceeds a preset threshold, a reminder signal is triggered and

sent to the controller. After receiving the reminder signal, the controller can adjust the wafer warpage

For example, the wafer warpage variation ΔBOW is the difference between the current wafer warpage and the initial warpage of the wafer 2. The heating power variation ΔP is the difference between the current heating power of the heating areas and the heating power of the heating areas in the initial state.

The above corresponding relationships are established based on experimental data. The experiment may include the following steps:

Taking the heating tray 1 including the central heating area 11 and the edge heating area 12 as an example, the heating tray 1 and the wafer 2 are arranged in a chamber. The wafer 2 that has not undergone thin film deposition is placed on the heating tray 1. After the temperature of the wafer 2 stabilizes to a target process temperature and the chamber stabilizes to a target process temperature, target pressure, target gas flow, and other conditions, the average heating power values of the inner heating coil and the outer heating coil on the heating tray 1 within a certain period of time are collected: $P_0'(C)$ and $P_0'(E)$. At this time, the wafer 2 is in a flat state, and the wafer warpage BOW_0 value of the wafer 2 is 0, where $P_0'(C)$ can be the heating power of the central heating area in the initial state, and $P_0'(E)$ can be the heating power of the edge heating area in the initial state;

a silicon nitride thin film with a known thickness is deposited on the wafer 2, and at this time, the wafer 2 warps upward (or downward), and the wafer warpage BOW_1 is known. After the wafer 2 stabilizes to the target process temperature, target pressure, target gas flow, and other conditions, the average heating power values of the inner heating coil and the outer heating coil on the heating tray 1 within a certain period of time are collected: $P_1(C)$ and $P_1(E)$;

then, a second layer of the same silicon nitride thin film is deposited on the wafer 2, and at this time, the wafer warpage BOW_2 is known, and the average heating power values of the inner heating coil and the outer heating coil on the heating tray 1 within a certain period of time are collected: $P_2(C)$ and $P_2(E)$;

by analogy, after n layers of known films are deposited on the wafer 2, BOW_n is known, and the average heating power values $P_n(C)$ and $P_n(E)$ of the inner heating coil and the outer heating coil on the heating tray 1 within a certain period of time are collected.

As shown in FIG. 5, through fitting, the relationships between the heating power values of the inner heating coil and the outer heating coil on the heating tray 1 and the variation of the wafer warpage BOW can be obtained: $P(C) = f1(BOW)$ and $P(E) = f2(BOW)$. Wherein, $f1$ indicates the relationship between $P(C)$ and BOW, $f2$ indicates the relationship between $P(E)$ and BOW, and $f1$ and $f2$ can be a kind of function, such as a linear function, a quadratic function, etc., which is not limited in the present application. It should be noted that $f1'$ is different from $f1$, and $f2'$ is different from $f2$.

During the thin film deposition, in addition to the influence of changes in heat transfer caused by the warpage of the wafer 2, the heating power of the heating tray 1 will also change due to the thermal influence of the plasma field, chemical reaction, flow field, and thermal field acting on the wafer 2 during the PECVD deposition. After the thermal influence becomes stable, the thermal influence brought by the plasma field, chemical reaction, flow field, and thermal field tends to be constant. At this time, changes in the heating power of the heating tray 1 are mainly affected by the variation of the wafer warpage BOW. Given the thermal influence, the relationships between the heating power values of the inner heating coil and the outer heating coil on the heating tray 1 and the variation of the wafer warpage BOW are expressed as:

$P(C) = f1(BOW) + C1$ and $P(E) = f2(BOW) + C2$, where $C1$ and $C2$ are the heating power constants of the influence brought by the plasma field, chemical reaction, flow field, and thermal field on the central heating area 11 and the edge heating area 12, respectively.

It should be noted that the thin film deposition process on the wafer in the present method includes a PECVD deposition process. During this process, each time a thin film is deposited, the plasma field, chemical reaction, flow field, and thermal field acting on the wafer 2 will bring thermal influence. Heat release during the thin film deposition is divided into three stages: first, the first deposition fluctuation stage, then the stable stage of thin film deposition, and finally the second deposition fluctuation

stage. The stable state of thermal influence here refers to the stable stage of thin film deposition. According to these embodiments, step S110 of real-time monitoring of the heating power change rate $\Delta P / P_0$ of each heating area on the heating tray 1 is executed only when it is determined that the film deposition reaction is in the stable stage of thin film deposition.

In some embodiments, the thin film deposition process on the wafer in the present method includes a CVD deposition process. During this process, each time a film is deposited, the chemical reaction, flow field, and thermal field acting on the wafer 2 will bring thermal influence. After the film deposition reaction becomes stable, the thermal influence brought by the chemical reaction, flow field, and thermal field tends to be constant. At this time, the change of the heating power on the heating tray 1 is mainly affected by the variation of the wafer warpage BOW. According to these embodiments, the step of real-time monitoring of the heating power change rate $\Delta P / P_0$ of each heating area on the heating tray 1 is executed only when it is determined that the thin film deposition reaction is in the stable stage of thin film deposition. Two formulas are obtained: $P(C) = f1(BOW) + C3$ and $P(E) = f2(BOW) + C4$, where C3 and C4 are the heating power constants of the influence brought by the chemical reaction, flow field, and thermal field on the central heating area 11 and the edge heating area 12, respectively.

During the CVD deposition, heat release during the thin film deposition is divided into three stages: first, the first deposition fluctuation stage, then the stable stage of thin film deposition, and finally the second deposition fluctuation stage. The stable state of the thermal influence here refers to the stable stage of thin film deposition.

To obtain the heating power variation, the heating power P_0 in the initial state is subtracted from the current heating power P , so that the constant terms C1 to C4 in the above formulas are eliminated, thereby eliminating the thermal influence of the plasma field, chemical reaction, flow field, thermal field, etc.

For example, $\Delta P(C) = (f1(BOW) + C1) - (f1(BOW_0) + C1) = f1(BOW) - f1(BOW_0)$, where BOW_0 is the initial warpage of the wafer 2.

Since $\Delta P(C) / P_0(C)$ equals $f1'(\Delta BOW)$, therefore,

$f1'(\Delta BOW) = (f1(BOW) - f1(BOW_0)) / P_0(C)$, which is an example showing the relationship between $f1$ and $f1'$.

During the thin film deposition, starting from the stable stage of thin film deposition, the heating power of the central heating area $P(C)$ and the heating power of the edge heating area $P(E)$ are read every x seconds, so as to monitor $\Delta P(C) / P_0(C)$ and $\Delta P(E) / P_0(E)$ in real time, and obtain the corresponding relationships of $\Delta P(C) / P_0(C) = f1''(\Delta BOW)$ and $\Delta P(E) / P_0(E) = f2''(\Delta BOW)$. The wafer warpage variation ΔBOW is calculated through $\Delta P(C)$ and $\Delta P(E)$. If ΔBOW exceeds the preset threshold, a reminder signal is triggered and sent to the controller. Wherein, $f1''$ indicates the relationship between $\Delta P(C) / P_0(C)$ and ΔBOW ; $f2''$ indicates the relationship between $\Delta P(E) / P_0(E)$ and ΔBOW .

In summary, this method for monitoring the wafer warpage does not require an additional measuring equipment and directly uses the changes in the heating power values of the inner heating coil and the outer heating coil on the heating tray 1 to calculate the wafer warpage variation ΔBOW in real time.

In some embodiments, when the wafer warpage variation ΔBOW exceeds the preset threshold, a reminder signal is triggered and sent to the controller. The method in the present application also determines the process conditions that need to be changed according to the mapping relationship between the wafer warpage variation ΔBOW and the process conditions, and processes the wafer according to the changed process conditions, so that the wafer warpage is controlled within the target warpage range.

Embodiment 2

This embodiment provides a method for real-time monitoring of the warpage of the wafer 2. As shown in FIG. 6, the method includes the following steps:

Step S210: During the thin film deposition on the wafer, monitor the wafer warpage variation ΔBOW in real time;

Step S220: If the wafer warpage variation ΔBOW exceeds a preset threshold,

determine the process conditions that need to be changed according to the mapping relationship between the wafer warpage variation ΔBOW and the process conditions, and process the wafer using the changed process conditions, so that the wafer warpage is controlled within the target warpage range.

When the warpage of the wafer 2 is within the target warpage range, the overall stress distribution of the wafer 2 is relatively uniform, and the wafer 2 is relatively flat, which can ensure the smooth progress of subsequent semiconductor manufacturing processes. The BOW value is used to indicate the warpage of the wafer 2.

The following takes a thin film deposition apparatus as an example to schematically illustrate the method for adjusting the warpage of the wafer 2 provided in the present application.

According to FIG. 7, the thin film deposition apparatus comprises: a chamber for thin film deposition; a gas supply assembly 3 for supplying process gas to the interior of the chamber; a heating tray 1 arranged below the gas supply assembly 3 for carrying and heating the wafer 2; a radio frequency source for providing radio frequency power (RF power) to excite the process gas in the chamber to dissociate into plasma and form a plasma field 4, and the plasma is deposited on the wafer 2 to form a thin film. The present application does not limit the position of the gas supply assembly 3. In some embodiments, the gas supply assembly 3 can be arranged on the top wall inside the chamber.

In step S220, the mapping relationship between the wafer warpage variation ΔBOW and the process conditions includes a first corresponding relationship and a second corresponding relationship. Wherein, the first corresponding relationship is the relationship between the wafer warpage variation ΔBOW and the thin film stress.

For example, the wafer warpage variation ΔBOW is positively correlated with the absolute value of the thin film stress. That is, ΔBOW increases as the thin film stress increases.

The second corresponding relationship is the relationship between the thin film stress and the process conditions.

For example, when a thin film is deposited on the wafer 2, the thin film stress can be divided into tensile stress and compressive stress. When the wafer 2 warps upward, the thin film stress is tensile stress; when the wafer 2 warps downward, the thin film stress is compressive stress.

For example, when the wafer 2 warps downward, the wafer warpage BOW is defined as a negative value, and when the wafer 2 warps upward, the wafer warpage BOW is defined as a positive value.

The process conditions in step S220 include but are not limited to any one or a combination of the gas flow rate, RF power, chamber pressure, gas composition ratio, film deposition time, terminal matching parameters, spacing between the gas supply assembly 3 and the wafer 2, etc.

For example, the terminal matching parameters include but are not limited to variable capacitor (C), frequency matcher, etc. The electric potential of the heating tray 1 is changed via the variable capacitor (C) to adjust the electric potential difference between the gas supply assembly 3 and the heating tray 1, thereby adjusting the distribution and energy of the plasma field 4 in the chamber, and thus changing the impact force of the plasma acting on the wafer 2. When the plasma is deposited on the wafer 2 to form a thin film, the thin film stress changes.

The frequency matcher is installed at the rear end of the radio frequency source, and the frequency matcher is adjusted to match the transmitting power supply of the radio frequency source and the frequency in the chamber. It should be noted that the interior of the above chamber is a vacuum environment.

For example, the thin film stress is positively correlated with the thin film deposition time. That is, the longer the film deposition time, the thicker the film layer, and the greater the corresponding thin film stress.

Different film materials (silicon nitride/silicon oxide/a-Si/carbon, etc.), different processes, and different composition ratios (recipe) have different response directions and sensitivities to the process conditions.

For example, in the second corresponding relationship, the thin film stress can

change with the process conditions. The relationship between the thin film stress and the process conditions can be a linear relationship or a non-linear relationship, which is specifically related to the influence of the process conditions on the thin film stress.

Taking the silicon nitride film layer as an example, the silicon nitride film layer is formed by introducing silane (SiH_4), ammonia (NH_3), and nitrogen (N_2) into the chamber at a certain ratio and flow rate, a set pressure and a set temperature are maintained, and plasma is formed through radio frequency (RF) to form a film. Experiments are carried out by adjusting the process conditions to monitor the stress and refractive index (RI) of the film layer in real time. Stress and RI both belong to the film layer properties. When a certain film layer is deposited, the purpose of adjusting the process conditions is to change the stress, but RI remains unchanged. For details, please refer to FIGS. 8–13. The unit of stress is MPa.

As shown in FIG. 8, the thin film stress is positively correlated with the flow rate of SiH_4 , that is, the thin film stress increases as the flow rate of SiH_4 increases. RI is positively correlated with the flow rate of SiH_4 , that is, RI increases as the flow rate of SiH_4 increases. Wherein, the unit of flow rate is sccm, and the flow rate units of different gases below are the same.

As shown in FIG. 9, the thin film stress is positively correlated with the flow rate of NH_3 , that is, the thin film stress increases as the flow rate of NH_3 increases. RI is negatively correlated with the flow rate of NH_3 .

As shown in FIG. 10, the thin film stress is negatively correlated with the flow rate of N_2 , that is, the thin film stress decreases as the flow rate of N_2 increases. RI is positively correlated with the flow rate of N_2 .

As shown in FIG. 11, the thin film stress is negatively correlated with RF power, that is, the thin film stress decreases as RF power increases. RI is positively correlated with RF power. Wherein, the unit of RF power is Watt (W).

As shown in FIG. 12, the thin film stress is positively correlated with the chamber pressure, that is, the thin film stress increases as the chamber pressure increases. RI is negatively correlated with the chamber pressure. Wherein, the unit of chamber pressure

is Torr.

As shown in FIG. 13, the thin film stress is positively correlated with the spacing between the gas supply assembly 3 and the wafer 2, that is, the thin film stress increases as the spacing increases. RI is negatively correlated with the spacing. Wherein, the unit of the spacing is mil.

The thin film stress is adjusted by means of the above relationship between the thin film stress and the process conditions, thereby adjusting the wafer warpage variation ΔBOW . For example, if the wafer warpage variation ΔBOW exceeds the preset threshold, the thin film stress value can be reduced by lowering the flow rate of SiH_4 and reducing the spacing, and the thin film stress can be changed from tensile stress to compressive stress, thereby reducing the wafer warpage variation ΔBOW or making ΔBOW equal 0, while keeping RI unchanged.

In addition to the thin film stress and RI, thin film properties also include etching rate (ER), extinction coefficient (EC), dielectric constant (k), etc. By experimentally studying the relationship between the above properties and the process conditions, when it is necessary to adjust the thin film stress without changing other properties, the process conditions that need to be adjusted can be calculated through the above relationships.

In some embodiments, before step S210 of real-time monitoring of the wafer warpage variation ΔBOW , the method further includes: obtaining the wafer warpage BOW in real time, and obtaining the wafer warpage variation ΔBOW according to the wafer warpage BOW.

During the thin film deposition on the wafer, a first film layer and a second film layer are alternately deposited to form a stacked structure. The first film layer provides tensile stress, and the second film layer provides compressive stress. The wafer warpage BOW is obtained in real time, and the warpage of the stacked structure is adjusted by adjusting the thin film deposition time to change the thickness of one of the film layers.

For example, the first film layer is a SiN film layer, and the second film layer is a

SiO₂ film layer. When the wafer warpage BOW is positive, increase the average thickness of the subsequent SiO₂ film layer or reduce the average thickness of the subsequent SiN film layer; when the wafer warpage BOW is negative, increase the average thickness of the subsequent SiN film layer or reduce the average thickness of the subsequent SiO₂ film layer, so that the wafer warpage is controlled within the target warpage range.

It should be noted that the first film layer is a type of film layer with tensile stress, and the second film layer is a type of film layer with compressive stress. The first film layer and the second film layer may include a plurality of film layers or a single film layer, and the number of film layers is not limited here.

In an optional embodiment, the heating tray 1 includes at least two heating areas, and in step S210, the wafer warpage variation ΔBOW is monitored according to the heating power change rate $\Delta P / P_0$ of the heating areas.

For example, the heating tray 1 includes a central heating area 11 and an edge heating area 12, and the edge heating area 12 is arranged on the outer periphery of the central heating area 11. Step S210 is specifically implemented as: monitor the heating power change rate $\Delta P(C) / P_0(C)$ of the central heating area 11 and the heating power change rate $\Delta P(E) / P_0(E)$ of the edge heating area 12 in real time, and determine the warpage state of the wafer 2 according to $\Delta P(C) / P_0(C)$ and $\Delta P(E) / P_0(E)$; if $|\Delta P(C) / P_0(C)|$ is greater than $|\Delta P(E) / P_0(E)|$, it is determined that the edge of the wafer 2 warps toward its back side and the middle is convex, that is, the wafer warps downward; if $|\Delta P(C) / P_0(C)|$ is smaller than $|\Delta P(E) / P_0(E)|$, it is determined that the edge of the wafer 2 warps toward its front side and the middle is concave, that is, the wafer warps upward.

The wafer warpage variation ΔBOW is calculated by the corresponding relationships of $\Delta P(C) / P_0(C) = f1''(\Delta BOW)$ and $\Delta P(E) / P_0(E) = f2''(\Delta BOW)$. If ΔBOW exceeds the preset threshold, a reminder signal is triggered and sent to the controller.

In some embodiments, after receiving the reminder signal, the controller activates a film formation process condition adjustment program, which, when executed, is used to obtain the mapping relationship between the wafer warpage variation ΔBOW and

the process conditions. Determine the process conditions that need to be changed according to the mapping relationship, and process the wafer 2 using the changed process conditions, so that the warpage of the wafer 2 is controlled within the target warpage range.

In an optional embodiment, the heating tray 1 includes an electrostatic chuck, and the process conditions in step S220 include the voltage of the electrostatic chuck. The method further includes: changing the voltage of the electrostatic chuck according to the wafer warpage variation ΔBOW , thereby improving the wafer warpage.

For example, the adsorption force of the heating tray 1 to the wafer 2 is improved by increasing the voltage of the electrostatic chuck, so as to improve the warpage state of the wafer 2 on the heating tray 1.

In summary, the warpage state of the wafer 2 in the chamber is monitored in real time during the thin film deposition. If the wafer warpage variation ΔBOW exceeds the preset threshold, the film formation process condition adjustment program is automatically activated to change the warpage state of the wafer 2, avoiding the problems of film quality deterioration and arc caused by the warpage of the wafer 2. Since the larger the film thickness, the more likely warpage occurs, the method for real-time monitoring of the warpage of the wafer 2 is more significant for film layers with high thin film stress and high thickness. Compared with Embodiment 1, Embodiment 2 provides a technical solution that not only obtains the wafer warpage and the variation of the wafer warpage, but also adjusts the process conditions according to these results to improve the wafer warpage.

Embodiment 3

Corresponding to the method for real-time monitoring of the warpage of the wafer 2 provided in Embodiment 2, this embodiment provides an apparatus for real-time monitoring of the warpage of the wafer 2. The apparatus for monitoring the warpage of the wafer 2 includes a memory, a monitor, a controller, and an operator.

The memory is configured to store at least one mapping relationship, which is the mapping relationship between the wafer warpage variation ΔBOW and the process

conditions.

For example, the apparatus for real-time monitoring of the warpage of the wafer 2 is used in the thin film deposition process, and the process conditions include any one or a combination of the gas flow rate, RF power, chamber pressure, gas composition ratio, terminal matching parameters, spacing between the gas supply assembly 3 and the wafer 2, etc.

The thin film deposition process is implemented by means of a thin film deposition apparatus. The film deposition apparatus comprises: a chamber for thin film deposition; a gas supply assembly 3 for supplying process gas to the interior of the chamber; a heating tray 1 arranged below the gas supply assembly 3 for carrying and heating the wafer 2; a radio frequency source for providing RF power to excite the process gas in the chamber to dissociate into plasma gas, and the plasma gas is deposited on the wafer 2 to form a thin film.

For example, the mapping relationship includes a first corresponding relationship and a second corresponding relationship, and the memory is also configured to store the first corresponding relationship and the second corresponding relationship.

The first corresponding relationship is the relationship between the wafer warpage variation ΔBOW and the thin film stress, and the second corresponding relationship is the relationship between the thin film stress and the process conditions.

The monitor is configured to monitor the wafer warpage variation ΔBOW .

For example, the monitor is configured to monitor the heating power change rate $\Delta P / P_0$ of each heating area on the heating tray, and determine the corresponding wafer warpage variation ΔBOW according to the heating power change rate $\Delta P / P_0$ of each area, wherein ΔP is the heating power variation of the heating area, P_0 is the heating power of the heating area in the initial state, the heating tray includes at least two heating areas, each heating area is in a set constant temperature control state, the wafer is arranged on at least two heating areas, and the wafer has a wafer area corresponding to each heating area.

The controller is configured to receive information from the monitor, and the

information includes the wafer warpage variation ΔBOW . The controller then activates the film formation process condition adjustment program and determines the process conditions to be changed according to the corresponding mapping relationship.

For example, the monitor is connected to the controller via electrical signals. There is a plurality of mapping relationships, and the controller determines the mapping relationship to be used from the plurality of mapping relationships, thereby determining the process conditions to be changed according to the mapping relationship.

The operator is configured to receive the changed process conditions from the controller and process the wafer 2 using the changed process conditions.

For example, the operator is connected to the controller via electrical signals. After receiving the changed process conditions, the operator inputs the corresponding process conditions into the thin film deposition apparatus. The process conditions are adjusted to change the thin film stress, thereby changing the warpage of the wafer 2.

In summary, during the thin film deposition, the warpage of the wafer 2 is monitored in real time. If the wafer warpage variation ΔBOW exceeds a preset threshold, activate the preset film formation process condition adjustment program, invoke the corresponding mapping relationship, and calculate and change the film formation process conditions, thereby changing the subsequent thin film stress, so that the warpage of the wafer 2 is controlled, and even the warped wafer 2 can be restored to a flat state by using the opposite film stress.

The basic concepts have been described above. Obviously, for those in the art, the above invention disclosure is only an example and does not constitute a limitation to the present application. Although not explicitly stated here, those in the art may make various modifications, improvements, and corrections to the present application. Such modifications, improvements, and corrections are suggested in the present application, so such modifications, improvements, and corrections still belong to the spirit and scope of the exemplary embodiments of the present application.

Besides this, the present application uses specific words to describe the

embodiments of the present application. For example, "an embodiment," "one embodiment," and/or "some embodiments" refer to a certain feature, structure, or characteristic related to at least an embodiment of the present application. Therefore, it should be emphasized and noted that the "one embodiment" or "an embodiment" or "one alternative embodiment" or "exemplary" mentioned twice or multiple times in different positions in this specification does not necessarily refer to the same embodiment. In addition, some features, structures, or characteristics in one or more embodiments of the present application can be properly combined.

Similarly, it should be noted that in order to simplify the disclosure of the present application and facilitate understanding of one or more invention embodiments, the description of the embodiments in the present application sometimes merges a plurality of features into one embodiment, drawing, or description thereof. However, this disclosure method does not mean that the object of the present application requires more features than those mentioned in the claims. In fact, the features of embodiments are fewer than all the features of a single embodiment disclosed above.

What is claimed is:

1. A method for real-time monitoring of wafer warpage, comprising:

during the thin film deposition on a wafer, monitoring the heating power change rate $\Delta P / P_0$ of each heating area on a heating tray in real time, wherein ΔP is the heating power variation of the heating area, P_0 is the heating power of the heating area in the initial state, the heating tray including at least two heating areas, each heating area being in a set constant temperature control state, the wafer being arranged on the at least two heating areas, and the wafer having a wafer area corresponding to each of the heating areas; and

determining whether the corresponding wafer area is detached from the heating tray according to the heating power change rate $\Delta P / P_0$.

2. The method for real-time monitoring of wafer warpage according to claim 1, wherein the step of determining whether the corresponding wafer area is detached from the heating tray according to the heating power change rate $\Delta P / P_0$ includes: when the heating power change rate $\Delta P / P_0$ is smaller than 0, the wafer area corresponding to the heating area is detached from the heating tray.

3. The method for real-time monitoring of wafer warpage according to claim 1, wherein the at least two heating areas include a central heating area and an edge heating area, and the edge heating area is arranged on the outer periphery of the central heating area;

the step of determining whether the corresponding wafer area is detached from the heating tray according to the heating power change rate $\Delta P / P_0$ includes:

if $|\Delta P(C) / P_0(C)|$ is greater than $|\Delta P(E) / P_0(E)|$, it is determined that the edge of the wafer warps toward its back side and the middle is convex; if $|\Delta P(C) / P_0(C)|$ is smaller than $|\Delta P(E) / P_0(E)|$, it is determined that the edge of the wafer warps toward its front side and the middle is concave; wherein, $\Delta P(C)$ indicates the heating power variation of the central heating area, $\Delta P(E)$ indicates the heating power variation of the edge heating area, $P_0(C)$ is the heating power of the central heating area in the initial

state, and $P_0(E)$ is the heating power of the edge heating area in the initial state.

4. The method for real-time monitoring of wafer warpage according to claim 3, further comprising: obtaining the corresponding relationship between the heating power change rate $\Delta P / P_0$ and the wafer warpage variation ΔBOW , and obtaining the wafer warpage variation ΔBOW corresponding to the current heating power change rate $\Delta P / P_0$ according to the corresponding relationship; if the wafer warpage variation ΔBOW exceeds a preset threshold, a reminder signal is triggered and sent to a controller.

5. The method for real-time monitoring of wafer warpage according to claim 4, wherein the corresponding relationship includes: $\Delta P(C) / P_0(C) = f1'(\Delta BOW)$ and $\Delta P(E) / P_0(E) = f2'(\Delta BOW)$, wherein $f1'$ indicates the relationship between $\Delta P(C) / P_0(C)$ and ΔBOW , and $f2'$ indicates the relationship between $\Delta P(E) / P_0(E)$ and ΔBOW .

6. The method for real-time monitoring of wafer warpage according to claim 1, wherein the thin film deposition process on the wafer includes a PECVD deposition process, and before the step of real-time monitoring of the heating power change rate $\Delta P / P_0$ of each heating area on the heating tray, the method further includes: determining that the thermal influence of the plasma field, chemical reaction, flow field, and thermal field on the heating tray is in a stable state.

7. The method for real-time monitoring of wafer warpage according to claim 1, wherein the thin film deposition process on the wafer includes a CVD deposition process, and before the step of real-time monitoring of the heating power change rate $\Delta P / P_0$ of each heating area on the heating tray, the method further includes: determining that the thermal influence of the chemical reaction, flow field, and thermal field on the heating tray is in a stable state.

8. The method for real-time monitoring of wafer warpage according to claim 4, wherein after receiving the reminder signal, the controller determines the process conditions that need to be changed according to the mapping relationship between the wafer warpage variation ΔBOW and the process conditions, and processes the wafer according to the changed process conditions, so that the wafer warpage is controlled within a target warpage range.

9. A method for real-time monitoring of wafer warpage, comprising:

during the thin film deposition on a wafer, monitoring the wafer warpage variation ΔBOW in real time;

if the wafer warpage variation ΔBOW exceeds a preset threshold, determining process conditions that need to be changed according to a mapping relationship between the wafer warpage variation ΔBOW and the process conditions and processing the wafer using the changed process conditions, so as to control the wafer warpage within a target warpage range.

10. The method for real-time monitoring of wafer warpage according to claim 9, wherein the mapping relationship includes a first corresponding relationship and a second corresponding relationship, wherein,

the first corresponding relationship includes the relationship between the wafer warpage variation ΔBOW and the thin film stress, and the second corresponding relationship includes the relationship between the thin film stress and the process conditions.

11. The method for real-time monitoring of wafer warpage according to claim 9, wherein the step of real-time monitoring of the wafer warpage variation ΔBOW includes: real-time monitoring of the heating power change rate $\Delta P / P_0$ of each heating area on the heating tray, and real-time monitoring of the wafer warpage variation ΔBOW according to the heating power change rate $\Delta P / P_0$, wherein the heating tray includes at least two heating areas, each heating area is in a set constant temperature control state, the wafer is arranged on the at least two heating areas, the wafer has a wafer area corresponding to each of the heating areas, ΔP is the heating power variation of the heating area, and P_0 is the heating power of the heating area in the initial state.

12. The method for real-time monitoring of wafer warpage according to claim 11, wherein the at least two heating areas include a central heating area and an edge heating area, and the edge heating area is arranged on the outer periphery of the central heating area;

the step of real-time monitoring of the wafer warpage variation ΔBOW further

includes:

if $|\Delta P(C) / P_0(C)|$ is greater than $|\Delta P(E) / P_0(E)|$, it is determined that the edge of the wafer warps toward its back side and the middle is convex; if $|\Delta P(C) / P_0(C)|$ is smaller than $|\Delta P(E) / P_0(E)|$, it is determined that the edge of the wafer warps toward its front side and the middle is concave, wherein $\Delta P(C) / P_0(C)$ indicates the heating power change rate of the central heating area, $\Delta P(E) / P_0(E)$ indicates the heating power change rate of the edge heating area, $P_0(C)$ is the heating power of the central heating area in the initial state, and $P_0(E)$ is the heating power of the edge heating area in the initial state.

13. The method for real-time monitoring of wafer warpage according to claim 12, further comprising: obtaining the corresponding relationship between the heating power change rate $\Delta P / P_0$ and the wafer warpage variation ΔBOW , and obtaining the wafer warpage variation ΔBOW corresponding to the current heating power change rate $\Delta P / P_0$ according to the corresponding relationship; if the wafer warpage variation ΔBOW exceeds the preset threshold, a reminder signal is triggered and sent to a controller.

14. The method for real-time monitoring of wafer warpage according to claim 13, wherein the corresponding relationship includes: $\Delta P(C) / P_0(C) = f1''(\Delta BOW)$ and $\Delta P(E) / P_0(E) = f2''(\Delta BOW)$, wherein $f1''$ indicates the relationship between $\Delta P(C) / P_0(C)$ and ΔBOW , and $f2''$ indicates the relationship between $\Delta P(E) / P_0(E)$ and ΔBOW .

15. The method for real-time monitoring of wafer warpage according to claim 9, wherein the process conditions include any one or a combination of the gas flow rate, RF power, chamber pressure, gas composition ratio, terminal matching parameters, and thin film deposition time.

16. The method for real-time monitoring of wafer warpage according to claim 11, wherein the heating tray is arranged below a gas supply assembly, and the gas supply assembly is used to supply the process gas deposited on the surface of the wafer; the process conditions include the spacing between the gas supply assembly and the wafer.

17. The method for real-time monitoring of wafer warpage according to claim 9,

wherein before the step of real-time monitoring of the wafer warpage variation ΔBOW , the method further includes: obtaining the wafer warpage BOW in real time, and obtaining the wafer warpage variation ΔBOW according to the wafer warpage BOW.

18. The method for real-time monitoring of wafer warpage according to claim 17, wherein during the thin film deposition on the wafer, a first film layer and a second film layer are alternately deposited to form a stacked structure, the first film layer has tensile stress, and the second film layer has compressive stress; the method further includes: when the wafer warpage BOW is positive, increasing the average thickness of the subsequent second film layer or reducing the average thickness of the subsequent first film layer; when the wafer warpage BOW is negative, increasing the average thickness of the subsequent first film layer or reducing the average thickness of the subsequent second film layer, so as to control the wafer warpage within the target warpage range.

19. The method for real-time monitoring of wafer warpage according to claim 18, wherein the first film layer is a SiN film layer, and the second film layer is a SiO₂ film layer.

20. The method for real-time monitoring of wafer warpage according to claim 10, wherein the wafer warpage variation ΔBOW is positively correlated with the absolute value of the thin film stress.

21. The method for real-time monitoring of wafer warpage according to claim 10, wherein the process conditions include the thin film deposition time, and the thin film stress is positively correlated with the thin film deposition time.

22. The method for real-time monitoring of wafer warpage according to claim 11, wherein the heating tray includes an electrostatic chuck, and the process conditions include the voltage of the electrostatic chuck; the method further includes: adjusting the voltage of the electrostatic chuck according to the wafer warpage variation ΔBOW .

23. An apparatus for real-time monitoring of wafer warpage, comprising:

a memory, configured to store at least one mapping relationship, and the mapping relationship being the mapping relationship between the wafer warpage variation

ΔBOW and the process conditions;

a monitor, configured to monitor the wafer warpage variation ΔBOW in real time;

a controller, configured to receive the wafer warpage variation ΔBOW , wherein if the wafer warpage variation ΔBOW exceeds a preset threshold, determine the process conditions that need to be changed according to the mapping relationship between the wafer warpage variation ΔBOW and the process conditions;

an operator, configured to receive the changed process conditions and process the wafer using the changed process conditions.

24. The apparatus for real-time monitoring of wafer warpage according to claim 23, wherein the mapping relationship includes a first corresponding relationship and a second corresponding relationship;

the first corresponding relationship includes the relationship between the wafer warpage variation ΔBOW and the thin film stress; the second corresponding relationship includes the relationship between the thin film stress and the process conditions.

25. The apparatus for real-time monitoring of wafer warpage according to claim 23, wherein the monitor is configured to monitor the heating power change rate $\Delta P / P_0$ of each heating area on the heating tray, and determine the corresponding wafer warpage variation ΔBOW according to the heating power change rate $\Delta P / P_0$ of each area, wherein ΔP is the heating power variation of the heating area, P_0 is the heating power of the heating area in the initial state, the heating tray includes at least two heating areas, each heating area is in a set constant temperature control state, the wafer is arranged on at least two heating areas, and the wafer has a wafer area corresponding to each of the heating areas.