

PULSED LASER-BASED ELLIPSOMETRY DEVICE AND ASSOCIATED OPTICAL OPERATION METHOD

Technical Field

- 5 **[0001]** The present disclosure relates to the field of optical measurement and detection, and more specifically to a pulsed laser-based ellipsometry device and its associated optical operation method.

Background Art

- 10 **[0002]** In an integrated circuit manufacturing process, in order to improve the chip yield, each process step needs to be monitored so that process problems can be discovered and solved in a timely manner before the manufacturing is completed. At present, non-contact optical measurement and detection techniques are used on a large scale to monitor process steps. Among them, ellipsometry systems are widely
15 used in coating process monitoring in a semiconductor production process to measure the thickness, optical constants and other properties of a film.

Summary of the Invention

- 20 **[0003]** An objective of the present disclosure is to provide a novel ellipsometry device and its related optical operation method, which can achieve ellipsometry at least in the case of pulsed laser.

- 25 **[0004]** According to a first aspect of the present disclosure, a pulsed laser-based ellipsometry device is provided. The ellipsometry device is configured to be operable to selectively work in an ellipsometry mode, and the ellipsometry device comprises: a pulse generation module adapted to generate a first laser pulse train having a first predetermined light intensity in the ellipsometry mode; a modulation module configured to receive the first laser pulse train and periodically modulate the first laser pulse train based on a first modulation signal, so as to obtain a modulated first laser pulse train, wherein the modulated first laser pulse train comprises at least
30 two laser pulses in each cycle; an incident module, comprising at least a polarizer and configured to make the modulated first laser pulse train, which has been at least polarized, incident on a sample; a reflection module, comprising at least an analyzer and configured to at least analyze an optical signal reflected or diffracted from the sample to obtain a processed optical signal; a first detector arranged downstream of

the reflection module to detect the processed optical signal and output a corresponding first detection signal; a lock-in amplification module configured to receive the first detection signal and perform lock-in amplification on the first detection signal to generate a noise-processed first detection signal on the basis that the first modulation signal is used as a reference signal; and a control and processing module configured to obtain information related to characteristics of the sample based on the noise-processed first detection signal.

[0005] It is easy to understand that ellipsometry can advantageously achieved in the case of pulsed laser using the ellipsometry device of the present disclosure.

Moreover, since the pulsed laser can also be used for pulse cleaning, this makes it possible for the ellipsometry device of the present disclosure to have both an ellipsometry mode and a pulse cleaning mode.

[0006] In some embodiments, the ellipsometry device is further configured to be operable to selectively work in a pulse cleaning mode; wherein the pulse generation module is adapted to generate a second laser pulse train having a second predetermined light intensity in the pulse cleaning mode, and wherein the second laser pulse train is arranged to be incident on the sample through the modulation module and the incident module, so as to clean an airborne molecular contamination layer on a surface of the sample.

[0007] In some embodiments, the pulse generation module comprises a pulsed laser and a light intensity controller, wherein the light intensity controller is arranged to be operable to selectively control a light intensity of a laser pulse train generated by the pulsed laser, so as to generate the first laser pulse train with the first predetermined light intensity or the second laser pulse train with the second predetermined light intensity.

[0008] In some embodiments, in the pulse cleaning mode, the modulation module is further configured to modulate the second laser pulse train based on a second modulation signal to obtain a modulated second laser pulse train, the modulated second laser pulse train being incident on the sample through the incident module, so as to clean the airborne molecular contamination layer on the surface of the sample.

[0009] In some embodiments, the first modulation signal is a periodic square wave signal, and the second modulation signal is a single square wave signal.

[0010] In some embodiments, the light intensity controller is selected from: a set of neutral filters mounted on a switchable structure; a set of continuously changing neutral filters mounted in a continuously changeable position; a combination of a polarizer and a $\lambda/2$ wave plate, wherein one of the polarizer and the $\lambda/2$ wave plate is rotatable; and a combination of an electro-optical modulator and a polarizer.

[0011] In some embodiments, the modulation module is selected from: a combination of an electro-optical modulator and a polarizer; and a chopper.

[0012] In some embodiments, the modulation frequency is less than one quarter of a pulsed laser repetition frequency.

[0013] In some embodiments, the incident module further comprises an optical splitter for splitting reference light from a light beam incident on the sample; and the ellipsometry device further comprises a second detector adapted to detect the reference light and output a second detection signal.

[0014] In some embodiments, the lock-in amplification module is further configured to receive the second detection signal, and to perform noise processing on the second detection signal and output a noise-processed second detection signal on the basis that the first modulation signal is used as a reference signal.

[0015] In some embodiments, the control and processing module is further configured to correct the noise-processed first detection signal based on the noise-processed second detection signal.

[0016] In some embodiments, the frequency of the first modulation signal is greater than a signal acquisition frequency of each of the first detector and the second detector.

[0017] In some embodiments, at least one of the incident module and the reflection module further comprises a phase compensator arranged to perform phase delay on polarization components of a corresponding light beam.

[0018] In some embodiments, at least one of the polarizer, the analyzer and the phase compensator is operable to rotate.

[0019] In some embodiments, the control and processing module is further configured to control the rotation of at least one of the polarizer, the analyzer and the phase compensator.

[0020] According to a second aspect of the present disclosure, a pulsed laser-based optical operation method is provided. The optical operation method comprises

a first operation method in an ellipsometry mode, wherein the first operation method comprises: generating a first laser pulse train having a first predetermined light intensity; periodically modulating the first laser pulse train based on a first modulation signal, so as to obtain a modulated first laser pulse train, wherein the
5 modulated first laser pulse train comprises at least two laser pulses in each cycle; at least using a polarizer to polarize the modulated first laser pulse train, and making the modulated first laser pulse train, which has been polarized, incident on a sample; at least using an analyzer to analyze an optical signal reflected or diffracted from the sample to obtain a processed optical signal; detecting the processed optical signal
10 and outputting a corresponding first detection signal; performing lock-in amplification on the first detection signal to generate a noise-processed first detection signal on the basis that the first modulation signal is used as a reference signal; and obtaining information related to characteristics of the sample based on the noise-processed first detection signal.

15 **[0021]** In some embodiments, the optical operation method further comprises a second operation method in a pulse cleaning mode, wherein the second operation method comprises: generating a second laser pulse train having a second predetermined light intensity; modulating the second laser pulse train using a second modulation signal to obtain a modulated second laser pulse train; and making the
20 modulated second laser pulse train incident on the sample, so as to clean an airborne molecular contamination layer on a surface of the sample.

[0022] In some embodiments, the optical operation method further comprises: operatively selecting one of the ellipsometry mode and the pulse cleaning mode.

[0023] In some embodiments, operatively selecting one of the ellipsometry
25 mode and the pulse cleaning mode comprises: adjusting a light intensity controller to control a light intensity of a laser pulse train generated from a pulsed laser.

[0024] In some embodiments, the optical operation method further comprises: optically splitting the modulated first laser pulse train, which has been polarized, to generate reference light; detecting the reference light to output a second detection
30 signal; and performing lock-in amplification on the second detection signal to generate a noise-processed second detection signal on the basis that the first modulation signal is used as a reference signal; and correct the noise-processed first detection signal based on the noise-processed second detection signal.

[0025] In some embodiments, at least using a polarizer to polarize the modulated first laser pulse train comprises: using a first phase compensator to generate a phase delay between two polarization components of the modulated first laser pulse train that has been polarized, and rotating one of the polarizer and the first phase compensator during the detection by the first detector; and/or at least using an analyzer to analyze an optical signal reflected or diffracted from the sample comprises: using a second phase compensator to generate a phase delay between two polarization components of the optical signal, and rotating one of the analyzer and the second phase compensator during the detection by the first detector.

[0026] It should also be understood that what is described in the Summary of the Invention is not intended to define key or important features of the embodiments of the present disclosure, and is not intended to limit the scope of the present disclosure. Other features of the embodiments of the present disclosure will be easily understood through the following description.

Brief Description of the Drawings

[0027] The foregoing and other features, advantages and aspects of embodiments of the present disclosure become more apparent with reference to the following detailed description and in conjunction with the accompanying drawings.

In the figures, the same or similar elements are denoted by the same or similar reference signs.

[0028] FIG. 1 shows a schematic structural diagram of a pulsed laser-based ellipsometry device according to an exemplary embodiment of the present disclosure.

[0029] FIG. 2 shows an illustration of various signals according to an exemplary embodiment of the present disclosure.

[0030] FIG. 3 shows an illustration of a pulsed laser-based optical operation method according to an exemplary embodiment of the present disclosure.

[0031] FIG. 4 shows a flowchart of a first operation method in a pulsed laser-based optical operation method according to an exemplary embodiment of the present disclosure.

[0032] FIG. 5 shows a flowchart of a second operation method in a pulsed laser-based optical operation method according to an exemplary embodiment of the present disclosure.

Detailed Description of Embodiments

[0033] Embodiments of the present disclosure are described in more detail below with reference to the accompanying drawings. Although some embodiments of the present disclosure are shown in the accompanying drawings, it should be understood that the present disclosure may be implemented in various forms and should not be construed as being limited to the embodiments set forth herein. Rather, these embodiments are provided for a more thorough and complete understanding of the present disclosure. It should be understood that the accompanying drawings and the embodiments of the present disclosure are only for exemplary purposes, and are not intended to limit the scope of protection of the present disclosure.

[0034] As mentioned above, ellipsometry systems are widely used in coating process monitoring in the semiconductor production process to measure the thickness, optical constants and other properties of a film. However, with the continuous development of semiconductor processes, in some scenarios, the thickness of the film used has reached the 1 nanometer or sub-nanometer level. The measurement performance of corresponding ellipsometry equipment then also needs to be improved. For example, for a film with a thickness of 1 nanometer, the measurement accuracy needs to be less than 0.003 nanometers.

[0035] For the above situation, a general broadband spectroscopy ellipsometry device has been unable to meet the requirements, and a single-wavelength ellipsometry device based on a single-wavelength laser needs to be used. For example, a type of ellipsometry device based on a single-wavelength laser has been described in the Patent Application No. CN 114427834 A. For ease of understanding, this application is incorporated herein by reference in its entirety.

[0036] Even so, when using the ellipsometry device, it is also necessary to eliminate airborne molecular contamination (AMC), because even in clean room environment, the air still contains water molecules, hydrocarbons, etc., which will settle to a surface of the film and form a contamination layer. The thickness of the contamination layer will increase with the exposure time of the film in the environment. Even inside the machine, a contamination layer will be formed, reaching 0.1 nanometer or more. In this way, the measurement results of the thickness of the film will be affected, resulting in measurement errors and false alarms.

[0037] However, most of the existing ellipsometry devices including the Patent Application No. CN 114427834 A are based on continuous laser and do not use pulsed laser. This is because it is difficult to solve the signal-to-noise ratio problem when using the pulsed laser for measurement. The disadvantage of this solution is that an additional laser cleaning device is required, that is, it is necessary to use two independent optical path systems, which will complicate the assembly process and work sequence, and also make the system require some additional diagnostic and monitoring procedures.

[0038] To this end, the present disclosure designs a pulsed laser-based ellipsometry device, which is distinguished in that the device can use pulsed laser to achieve single-wavelength ellipsometry. In addition, due to the use of the pulsed laser, the device can also have a function of cleaning an AMC layer without the need for additional cleaning modules.

[0039] FIG. 1 shows a schematic structural diagram of a pulsed laser-based ellipsometry device according to an exemplary embodiment of the present disclosure.

[0040] It will be understood that the ellipsometry device 100 of the present disclosure may be configured to be operable to selectively work in an ellipsometry mode or a pulse cleaning mode. In this case, the ellipsometry device 100 may be operated to be selectively switched from the ellipsometry mode to the pulse cleaning mode, or from the pulse cleaning mode to the ellipsometry mode. However, it will be understood that although the ellipsometry device 100 of the present disclosure is designed to have both the ellipsometry mode and the pulse cleaning mode, in some particular embodiments, the ellipsometry device 100 only having the function of either the ellipsometry mode or the pulse cleaning mode is also possible.

[0041] By way of example only, as shown in FIG. 1, the ellipsometry device 100 may mainly comprise a pulse generation module 10, a modulation module 20, an incident module 30, a reflection module 40, a first detector 50, and a lock-in amplification module 60, and a control and processing module 70.

[0042] Specifically, the pulse generation module 10 may be configured to generate a first laser pulse train having a first predetermined light intensity in the ellipsometry mode, or to generate a second laser pulse train having a second predetermined light intensity in the pulse cleaning mode.

[0043] Typically, the pulse generation module 10 may comprise, for example, a pulsed laser 101 and a light intensity controller 102.

[0044] The function of the pulsed laser 10 is to generate a laser pulse of a predetermined wavelength. By way of example only, the predetermined wavelength
5 may be, for example, a single wavelength of 355 nm, 535 nm, and 632 nm; and the pulse width may be, for example, nanosecond, femtosecond, or picosecond level. In particular, in some embodiments, the repetition frequency of the pulsed laser may be greater than 1 MHz, which may facilitate the subsequent working of the lock-in amplification module 60.

10 **[0045]** The function of the light intensity controller 102 is to control the light intensity of the laser pulse generated by the pulsed laser 101. Typically, light intensity controller 102 is an attenuator. In some embodiments, the light intensity controller 102 may selected from: a set of neutral filters mounted on a switchable structure; a set of continuously changing neutral filters mounted in a continuously
15 changeable position; a combination of a polarizer and a $\lambda/2$ wave plate, wherein one of the polarizer and the $\lambda/2$ wave plate is rotatable; and a combination of an electro-optical modulator and a polarizer. By way of example only, the switchable structure, the set of continuously changing neutral filters, or the rotation of one of the polarizer and the $\lambda/2$ wave plate can be controlled by means of a motor, for example.

20 **[0046]** Depending on the mode in which the ellipsometry device 100 is intended to work, that is, the ellipsometry mode or the pulse cleaning mode, the light intensity controller 102 can be operated such that the light intensity output by the pulse generation module 10 is at the first predetermined light intensity or the second predetermined light intensity. Generally speaking, the second predetermined light
25 intensity is generally greater than the first predetermined light intensity, so that it is possible to more advantageously clean the airborne molecular contamination layer on the surface of the sample. It will be understood that once the light intensity controller 102 is operated such that the light intensity output by the pulse generation module 10 is at the first predetermined light intensity, the ellipsometry device 100
30 can be regarded as being placed in the ellipsometry mode, and once the light intensity controller 102 is operated such that the light intensity output by the pulse generation module 10 is at the second predetermined light intensity, the ellipsometry device 100 can be regarded as being placed in the pulse cleaning mode. In addition to the aforementioned ellipsometry mode and pulse cleaning mode, in some

embodiments, the ellipsometry device 100 of the present disclosure may also be configured to operate in a test mode, in which the light intensity controller 102 can be adjusted to optimize the light intensity output by the pulse generation module 10, so as to select a first predetermined light intensity suitable for the ellipsometry mode and a second predetermined light intensity suitable for the pulse cleaning mode.

[0047] The modulation module 20 may be arranged downstream of the pulse generation module 10 to receive and modulate the laser pulse train output from the pulse generation module 10. As will be understood with reference to the following description, the function of the modulation module 20 is to combine with the lock-in amplification module 60 to denoise the detection optical signal reflected or diffracted from the sample. By way of example only, in some embodiments, the modulation module 20 may be selected, for example, from: a combination of an electro-optical modulator and a polarizer, and a chopper.

[0048] In the ellipsometry mode, the modulation module 20 may be configured to receive the first laser pulse train and periodically modulate the first laser pulse train based on a first modulation signal, so as to obtain a modulated first laser pulse train. In some embodiments, the first modulation signal may be generated by the modulation module 20 itself. In some further embodiments, the modulation module 20 may receive the first modulation signal from the outside (e.g., the control and processing module 70). In particular, the modulation frequency of the first modulation signal needs to be less than one quarter of the laser pulse repetition frequency to ensure that the modulated first laser pulse train comprises at least two laser pulses in each cycle. Still in particular, the modulation frequency of the first modulation signal also needs to be greater than a sampling frequency of each of the first detector and the second detector that will be described later, to ensure the integrity and reliability of signal sampling. By way of example only, the first modulation signal may be, for example, a periodic square wave signal.

[0049] In the pulse cleaning mode, the modulation module 20 may be configured to receive the second laser pulse train and periodically modulate the second laser pulse train based on a second modulation signal, so as to obtain a modulated second laser pulse train. Subsequently, the modulated second laser pulse train may be incident on the sample through the incident module, so as to clean the airborne molecular contamination layer on the surface of the sample. In some embodiments, the second modulation signal may be a single square wave signal. It

can be understood that the time for cleaning the airborne molecular contamination layer on the surface of the sample can be controlled by adjusting the width of the single square wave signal, thereby achieving the purpose of cleaning.

[0050] It will also be understood that whether in the ellipsometry mode or the pulse cleaning mode, an incident light path and modules on the incident light path are shared. This enables convenient switching between the ellipsometry mode and the pulse cleaning mode of the present disclosure. It will also be understood that in the pulse cleaning mode, the incident module 30 only functions as an incident path, and a reflection light path is unnecessary. Therefore, the reflection light path or modules on the reflection light path can be turned off in this mode, and the functions and configurations of other modules in the ellipsometry device will be mainly described below using the ellipsometry mode.

[0051] In some embodiments, an adjustable reflecting mirror 103 may be arranged before the pulse generation module 10 and the modulation module 20 to facilitate adjustment of the direction of the light beam incident on the sample. Those skilled in the art can easily understand that the reflecting mirror 103 may also be arranged in another position along the light path incident on the sample.

[0052] The incident module 30 may comprise at least a polarizer 105, and is configured to make the modulated first laser pulse train, which has been at least polarized, incident on the sample. In some embodiments, in addition to the polarizer 105, incident module 30 may optionally comprise one or more of a first phase compensator 107 and a first objective lens 108. In particular, the polarizer 105, the first phase compensator 107 and the first objective lens 108 may be sequentially arranged along the incident light path.

[0053] Correspondingly, the reflection module 40 may comprise at least an analyzer 111, and is configured to at least analyze an optical signal reflected or diffracted from the sample to obtain a processed optical signal. In some embodiments, in addition to the analyzer 111, the reflection module 30 may optionally comprise one or more of a second objective lens 109 and a second phase compensator 110. In particular, the second objective lens 109, the second phase compensator 110 and the analyzer 111 may be sequentially arranged along the reflection light path reflected from the sample.

[0054] It is easy to understand that the function of the polarizer 105 and the analyzer 111 is to limit the polarization direction of the light emitted therefrom to a

certain linear polarization direction; the function of the first phase compensator 107 and the second phase compensator 110 is to cause an amount of phase delay between two polarization components of the light incident thereon, which amount of delay is related to its azimuth angle, and if the phase compensator is rotated, the amount of delay between the polarization components of the light emerging therefrom will change periodically, that is, the polarization state of emergent light changes periodically; and the function of the first objective lens 108 is to converge the light beam into a small spot on the sample to be measured, and the function of the second objective lens 109 is to collimate the light reflected or diffracted back from the sample.

[0055] It should be understood that the aforementioned specific arrangement of both the incident module 30 and the reflection module 40 is a typical configuration of the ellipsometry device, and the ellipsometry device may have different ellipsometry structures depending on its specific configuration.

[0056] For example, in an embodiment in which the key components of the incident module and the reflection module comprise the polarizer 105, the first objective lens 108, the second objective lens 109, the analyzer 111 and the first detector 112, if the polarizer 105 or the analyzer 111 rotates during measurement, then the ellipsometry device has a P_RSA or PSA_R ellipsometric configuration, where P represents the polarizer, S represents the sample, A represents the analyzer, and R represents rotation.

[0057] For another example, in an embodiment in which the key components of the incident module and the reflection module comprise the polarizer 105, the first phase compensator 107 or the second phase compensator 110, the first objective lens 108, the second objective lens 109, the analyzer 111 and the first detector 112, if the first phase compensator 107 or the second phase compensator 110 rotates during measurement, the ellipsometry device has a PC_RSA or PSC_RA ellipsometric configuration.

[0058] For another example, in an embodiment in which the key components of the incident module and the reflection module comprise the polarizer 105, the first phase compensator 107, the first objective lens 108, the second objective lens 109, the second phase compensator 110, the analyzer 111 and the first detector 112, if both the first phase compensator 107 and the second phase compensator 110 rotate

during measurement, the ellipsometry device has a $PC_{RSC_{RA}}$ ellipsometric configuration, and is also known as a Mueller matrix ellipsometer.

5 **[0059]** In addition, in the incident module 30 and the reflection module 40 described above, a light collector 113 may also be configured respectively for the polarizer 105 and the analyzer 111, so as to collect light that does not pass through the polarizer 105 or the analyzer 111, that is, leaked light or waste light.

10 **[0060]** The first detector 50 is arranged downstream of the reflection module 40 to detect the processed optical signal and output a corresponding first detection signal. By way of example only, the first detector may be a CCD, a CMOS sensor, or any other sensor that may be used to detect an optical signal, such as a phototube.

15 **[0061]** Here, those skilled in the art will understand that since a laser pulse is used as a light beam incident on the sample, the optical signal from the sample that is detected by the first detector 50 will exhibit a low signal-to-noise ratio.

20 **[0062]** In order to achieve a high signal-to-noise ratio, a lock-in amplification module 60 is specifically designed in the present disclosure. The lock-in amplification module 60 is configured to receive the first detection signal and perform lock-in amplification on the first detection signal to generate a noise-processed first detection signal on the basis that the first modulation signal is used as a reference signal. In some embodiments, the lock-in amplification module 60 may also be coupled to the modulation module 20 to receive the first modulation signal as a reference signal.

25 **[0063]** Subsequently, the control and processing module 70 may be configured to obtain information related to characteristics of the sample based on the noise-processed first detection signal. Specifically, the control and processing module 70 can convert the noise-processed first detection signal into Fourier coefficients, and then calculate parameter information related to the sample to be measured. The parameter information may include, but is not limited to, the thickness, optical constants, etc. of the film.

30 **[0064]** In addition, the control and processing module 70 may also be configured to control the working mode, triggering and parameter adjustment of the relevant hardware in the ellipsometry device, so as to achieve normal working in the ellipsometry mode and the pulse cleaning mode. For example, the related hardware may include but is not limited to: the pulsed laser 101 and the light intensity controller 102 in the pulse generation module 10, the polarizer 105 and the first

phase compensator 107 in the incident module 30, the second phase compensator 110 and the analyzer 111 in the reflection module 40, the first detector 50, the lock-in amplification module 60, etc.

[0065] In some embodiments, the control and processing module 70 may further be composed of a signal acquisition and processing module 116 and a control module 117. The signal acquisition and processing module 116 may be used to perform further signal acquisition and processing on the noise-processed first detection signal output from the lock-in amplification module 60, so as to convert the noise-processed first detection signal into Fourier coefficients, and then calculate parameter information related to the sample to be measured. The control module 117 may be used to control the working mode, triggering and parameter adjustment of each hardware in order to obtain the final data.

[0066] For example, the control module 117 may control the switching of an optical filter in the light intensity controller 10 (for example, by means of a switchable mechanism) or the voltage of the electro-optical modulator, so as to achieve control of the light intensity output by the pulse generation module. For another example, the control module 117 may control the rotation of corresponding apparatuses in the polarizer 105, the first phase compensator 107, the second phase compensator 110 and the analyzer 111 in different ellipsometric configurations (for example, this can be realized by controlling relevant rotation motors of the apparatuses) to achieve the detection of optical signals from the sample at different azimuth angles of the corresponding apparatuses. At the same time, the control module 117 may also synchronously control the first detector 50, the lock-in amplification module 60 and the signal acquisition and processing module 116 to achieve synchronous triggering of the apparatuses.

[0067] In order to obtain detection results more accurately, in some embodiments, the incident module 30 may further comprise an optical splitter 106 for splitting reference light from the light beam incident on the sample. As will be described later, the function of the reference light is to correct the light intensity fluctuation of the measurement light incident on the sample.

[0068] In some embodiments, the optical splitter 106 may be arranged behind the polarizer 105, which is advantageous for making the measurement light and the reference light incident on the sample be linearly polarized light from the same direction. Further, a splitting surface of the optical splitter 106 may be arranged

parallel or perpendicular to the polarization direction of the light output from the polarizer 105, which helps to eliminate the change of the polarization state of the incident light by the optical splitter, that is, to eliminate the polarization interference of the optical splitter, thereby maintaining the original polarization direction of the light output from the polarizer, and ensuring the measurement accuracy of the system. It should be noted that it is possible that the splitting surface of the optical splitter is not parallel or perpendicular to the polarization direction of the light output from the polarizer. This can subsequently be corrected to remove the polarization interference from the optical splitter.

10 **[0069]** The ellipsometry device 100 may further comprise a second detector 114, which may be used to detect the reference light and output a second detection signal. Further, the second detection signal will be output to the lock-in amplification module 60 to perform noise processing using the principle of lock-in amplification. Specifically, similar to the first detection signal, the first modulation signal can also
15 be used as the reference signal. Still further, the control and processing module 70 may be further configured to correct the noise-processed first detection signal based on the noise-processed second detection signal.

[0070] It will be understood that since the reference light and the measurement light are light coming from the same light source (more specifically, they may be polarized light from the same polarization direction), with the above correction method, the intensity fluctuation originating from the light source in the first detection signal can be effectively corrected, which improves the system measurement stability, thereby implementing an ellipsometry system with ultra-high stability.

25 **[0071]** In addition, in order to achieve precise data synchronization, the present disclosure also designs a dual-channel data clock synchronization solution, that is, the data collected by the first detector and the data collected by the second detector have synchronized clocks. For example, in some embodiments, the first detector and the second detector may share a clock source in the control and processing module
30 70 to synchronously acquire data, that is, to achieve synchronous acquisition of the measurement light and the reference light. Further, in some further embodiments, it is also possible to use, for example, the same clock signal to synchronize the operations of the lock-in amplification module 60 and the signal acquisition and processing module 116.

[0072] It should be noted that the present disclosure is not limited to the above-mentioned synchronization solution, any solution used to synchronize the polarizer 105, the first phase compensator 107, one of the second compensator 110 and the analyzer 111, and the data acquisition of the first detector and the second detector, and to synchronize the operations of both the lock-in amplification module 60 and the signal acquisition and processing module 116 should fall within the scope of protection of the present application.

[0073] In order to better understand the signals employed or output by the relevant apparatuses of the present disclosure, FIG. 2 shows an illustration of various signals according to an exemplary embodiment of the present disclosure.

[0074] The various components and specific structures in the ellipsometry device according to the exemplary embodiment of the present disclosure have been described in detail above. A pulsed laser-based optical operation method according to an exemplary embodiment of the present disclosure will be briefly described below with reference to FIGS. 3 to 5. It should be understood that the optical operation method of the present disclosure corresponds to the above ellipsometry device. Therefore, the relevant method steps in the optical operation method of the present disclosure can be performed by corresponding modules of the above ellipsometry device.

[0075] Specifically, as shown in FIG. 3, the optical operation method 300 of the present disclosure may comprise a first operation method 310 in the ellipsometry mode and a second operation method 320 in the pulse cleaning mode. In some embodiments, the method 300 may further comprise selecting either of the ellipsometry mode and the pulse cleaning mode. In still other embodiments, the method 300 may further comprise switching between the ellipsometry mode and the pulse cleaning mode as required. In particular, the above selection or switching operation may be performed by adjusting the light intensity controller in the pulse generation module. Once the light intensity is adjusted to correspond to the ellipsometry mode or the pulse cleaning mode, it means that the operation of a corresponding mode can be performed.

[0076] Specifically, as shown in FIG. 4, the first operation method 310 may comprise the following steps.

[0077] At block 311, a first laser pulse train having a first predetermined light intensity is generated. In some embodiments, this step may be performed by the

pulse generation module 10 described above. In particular, the pulse generation module 10 may comprise a pulsed laser and a light intensity modulator. The light intensity modulator may be used to modulate the light intensity generated by the pulsed laser.

5 **[0078]** At block 312, the first laser pulse train is periodically modulated based on a first modulation signal, so as to obtain a modulated first laser pulse train.

[0079] In some embodiments, the first laser pulse train may be periodically modulated by the modulation module 20, so as to obtain the modulated first laser pulse train. In some further embodiments, the modulated first laser pulse train
10 comprises at least two laser pulses in each cycle. In some further embodiments, the first modulation signal may come from the modulation module 20 itself, or may be received from the outside. In some further embodiments, the modulation frequency of the first modulation signal needs to be less than one quarter of the laser pulse repetition frequency to ensure that the modulated first laser pulse train comprises at
15 least two laser pulses in each cycle. In addition, the modulation frequency of the first modulation signal also needs to be greater than the sampling frequency of each of the first detector and the second detector described above, to ensure the integrity and reliability of signal sampling.

[0080] At block 313, at least a polarizer is used to polarize the modulated first laser pulse train, and make the modulated first laser pulse train, which has been polarized, incident on a sample. As an example, this step may be performed in the
20 incident module 30 comprising the polarizer described above.

[0081] Accordingly, at block 314, at least an analyzer is used to analyze an optical signal reflected or diffracted from the sample to obtain a processed optical
25 signal. As an example, this step may be performed in the reflection module 40 comprising the analyzer described above.

[0082] Depending on the different ellipsometric configurations of the ellipsometry device 100, different configurations may be performed in the incident module 30 and the reflection module 40. For example, the different ellipsometric
30 configurations may include, but are not limited to: PC_{RSA} , PSC_{RA} or $PC_{RSC_{RA}}$.

[0083] In some embodiments, at least using a polarizer to polarize the modulated first laser pulse train may comprise: using a first phase compensator to generate a phase delay between two polarization components of the modulated first

laser pulse train that has been polarized, and rotating one of the polarizer and the first phase compensator during the detection by the first detector.

[0084] In some further embodiments, at least using an analyzer to analyze an optical signal reflected or diffracted from the sample may comprise: using a second
5 phase compensator to generate a phase delay between two polarization components of the optical signal, and rotating one of the analyzer and the second phase compensator during the detection by the first detector.

[0085] Subsequently, at block 315, the processed optical signal is detected and a corresponding first detection signal is output. As an example, this step may be
10 performed by the first detector 50 described above. The first detector 50 may be, for example, a CCD, CMOS, or other sensors.

[0086] Next, at block 316, lock-in amplification is performed on the first detection signal to generate a noise-processed first detection signal on the basis that the first modulation signal is used as a reference signal. As an example, this step
15 may be performed by the lock-in amplification module 60 described above. It can be understood that the lock-in amplification module 60 can effectively remove high-frequency noise from the detected signal, thereby obtaining a noise-processed first detection signal with a higher signal-to-noise ratio.

[0087] Finally, at block 317, . As an example, this step may be performed, for
20 example, in the signal acquisition and processing module 116 in the control and processing module 70 described above. The information related to the characteristics of the sample includes but is not limited to: the thickness, optical constants, etc. of the film.

[0088] In addition, in some embodiments in which the information related to
25 the characteristics of the sample is obtained based on the noise-processed first detection signal, the first operation method 320 may further comprise: optically splitting the modulated first laser pulse train, which has been polarized, to generate reference light; detecting the reference light to output a second detection signal; and performing lock-in amplification on the second detection signal to generate a noise-processed second detection signal on the basis that the first modulation signal is used
30 as a reference signal; and correct the noise-processed first detection signal based on the noise-processed second detection signal.

[0089] It should be understood that the optically splitting step may be carried out by the optical splitter described above; the detection of the reference light may

be carried out by the second detector described above; the operation of lock-in amplification of the second detection signal may be carried out by the lock-in amplification module described above; and the correction of the noise-processed first detection signal may be carried out by the signal acquisition and processing module in the control and processing module described above.

[0090] As shown in FIG. 5, the second operation method 320 may comprise:

[0091] At block 321, a second laser pulse train having a second predetermined light intensity is generated.

[0092] In some embodiments, this step may be generated by the pulse generation module 10 described above. In particular, the pulse generation module 10 may comprise a pulsed laser and a light intensity modulator. The light intensity modulator may be used to modulate the light intensity generated by the pulsed laser, so as to generate the second laser pulse train having the second predetermined light intensity.

[0093] At block 322, the second laser pulse train is modulated using a second modulation signal to obtain a modulated second laser pulse train.

[0094] In some embodiments, this step may be performed by the modulation module 20 described above. Similarly, the second modulation signal may be generated by the modulation module 20 itself, or may be received from the outside.

[0095] Next, at block 333, the modulated second laser pulse train is incident on the sample, so as to clean an airborne molecular contamination layer on a surface of the sample.

[0096] In some embodiments, this step may be performed, for example, by the incident module 30. In this way, it is easy to understand that this means that both the ellipsometry mode and the pulse washing mode can share the incident light path. This makes it simple to switch between the ellipsometry mode and the pulse washing mode, and allows the cost of the entire ellipsometry device to be reduced.

[0097] Various embodiments of the pulsed laser-based ellipsometry device and the related optical operation method have been described in detail above. It will be understood that in the solutions of the present disclosure, a pulsed laser is used to achieve ellipsometry and a lock-in amplification module is used to achieve noise suppression, thereby improving the performance of ellipsometry. In addition, technologies such as accurately synchronized reference light, dual-channel clock synchronization, and polarization interference of the optical splitter are also used in

the present disclosure, further improving the performance of ellipsometry. It is easy to understand that the solutions of the present disclosure can easily meet the film measurement requirements of advanced process nodes. In addition, it can also be understood that due to the use of the pulsed laser, this device can realize the laser cleaning function without the need for additional light paths, and the system is convenient and simple.

5 [0098] In addition, the procedures of the pulsed laser-based ellipsometry method or optical operation method of the present disclosure have also been described in detail. It will be understood that the procedures described above are merely examples. Although the steps of the method are described in a particular order in the description, this does not require or imply that the operations must be performed in that particular order, or that all illustrated operations must be performed to achieve desired results. Rather, the steps depicted may be performed in a different order. Additionally or alternatively, some steps can be omitted, a plurality of steps can be incorporated as one step for execution, and/or one step can be subdivided into a plurality of steps for execution.

15 [0099] While the present invention has been illustrated and described in detail in the accompanying drawings and the foregoing description, these illustrations and descriptions are to be considered illustrative or exemplary rather than restrictive; and the present invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and practiced by those skilled in the art in practicing the claimed invention, from a study of the accompanying drawings, the disclosure, and the appended claims.

20 [0100] In the claims, the word “comprising” does not exclude other elements, and the indefinite article “a” or “an” does not exclude a plurality. A single element or other units may fulfill the functions of multiple items recited in the claims. The mere fact that certain features are recited in mutually different embodiments or dependent claims does not mean that a combination of these features cannot be used to advantage. Without departing from the spirit and scope of the present application, the scope of protection of the present application covers any possible combination of the individual features stated in the individual embodiments or dependent claims.

30 [0101] Furthermore, any reference signs in the claims shall not be construed as limiting the scope of the present invention.

CLAIMS

1. A pulsed laser-based ellipsometry device, wherein the ellipsometry device is configured to be operable to selectively work in an ellipsometry mode, and
5 the ellipsometry device comprises:
a pulse generation module (10) adapted to generate a first laser pulse train having a first predetermined light intensity in the ellipsometry mode;
a modulation module (20) configured to receive the first laser pulse train and periodically modulate the first laser pulse train based on a first modulation signal,
10 so as to obtain a modulated first laser pulse train, wherein a modulation frequency of the first modulation signal is less than one quarter of a laser pulse repetition frequency;
an incident module (30) comprising at least a polarizer (105) and configured to make the modulated first laser pulse train, which has been at least polarized, incident
15 on a sample;
a reflection module (40) comprising at least an analyzer (111) and configured to at least analyze an optical signal reflected or diffracted from the sample to obtain a processed optical signal;
a first detector (50) arranged downstream of the reflection module (40) to detect
20 the processed optical signal and output a corresponding first detection signal;
a lock-in amplification module (60) configured to receive the first detection signal and perform lock-in amplification on the first detection signal to generate a noise-processed first detection signal on the basis that the first modulation signal is used as a reference signal; and
25 a control and processing module (70) configured to obtain information related to characteristics of the sample based on the noise-processed first detection signal;
wherein the modulation frequency of the first modulation signal is greater than a signal acquisition frequency of the first detector.
- 30 2. The ellipsometry device according to claim 1, wherein the ellipsometry device is further configured to be operable to selectively work in a pulse cleaning mode;

wherein the pulse generation module (10) is adapted to generate a second laser pulse train having a second predetermined light intensity in the pulse cleaning mode, and

5 wherein the second laser pulse train is arranged to be incident on the sample through the modulation module (20) and the incident module (30), so as to clean an airborne molecular contamination layer on a surface of the sample.

3. The ellipsometry device according to claim 2, wherein the pulse generation module (10) comprises a pulsed laser (101) and a light intensity controller
10 (102),

wherein the light intensity controller (102) is arranged to be operable to selectively control a light intensity of a laser pulse train generated by the pulsed laser (101), so as to generate the first laser pulse train having the first predetermined light intensity or the second laser pulse train having the second predetermined light
15 intensity.

4. The ellipsometry device according to claim 3, wherein in the pulse cleaning mode, the modulation module (20) is further configured to modulate the second laser pulse train based on a second modulation signal to obtain a modulated
20 second laser pulse train, the modulated second laser pulse train being incident on the sample through the incident module (30), so as to clean the airborne molecular contamination layer on the surface of the sample.

5. The ellipsometry device according to claim 4, wherein
25 the first modulation signal is a periodic square wave signal, and the second modulation signal is a single square wave signal.

6. The ellipsometry device according to claim 4, wherein the light intensity controller (102) comprises a set of neutral filters mounted on a switchable
30 structure.

7. The ellipsometry device according to claim 4, wherein the light intensity controller (102) comprises a set of continuously changing neutral filters mounted in a continuously changeable position.

8. The ellipsometry device according to claim 4, wherein the light intensity controller (102) comprises a combination of a polarizer and a $\lambda/2$ wave plate, wherein one of the polarizer and the $\lambda/2$ wave plate is rotatable.

5

9. The ellipsometry device according to claim 4, wherein the light intensity controller (102) comprises a combination of an electro-optical modulator and a polarizer.

10 10. The ellipsometry device according to claim 6, wherein the modulation module (20) is selected from:

a combination of an electro-optical modulator and a polarizer; and
a chopper.

15 11. The ellipsometry device according to claim 6, wherein the incident module (30) further comprises an optical splitter (106) for splitting reference light from a light beam incident on the sample; and

the ellipsometry device further comprises a second detector (114) adapted to detect the reference light and output a second detection signal.

20

12. The ellipsometry device according to claim 11, wherein the lock-in amplification module (60) is further configured to receive the second detection signal, and to perform noise processing on the second detection signal and output a noise-processed second detection signal on the basis that the first modulation signal
25 is used as a reference signal.

13. The ellipsometry device according to claim 12, wherein the control and processing module (70) is further configured to correct the noise-processed first detection signal based on the noise-processed second detection signal.

30

14. The ellipsometry device according to any one of claims 11-13, wherein the modulation frequency of the first modulation signal is greater than a signal acquisition frequency of the second detector.

15. The ellipsometry device according to claim 4, wherein at least one of the incident module (30) and the reflection module (40) further comprises a phase compensator arranged to generate a phase delay between polarization components of a corresponding light beam.

5

16. The ellipsometry device according to claim 15, wherein at least one of the polarizer (105), the analyzer (111) and the phase compensator is operable to rotate.

10

17. The ellipsometry device according to claim 16, wherein the control and processing module (70) is further configured to control the rotation of at least one of the polarizer (105), the analyzer (111) and the phase compensator.

18. A pulsed laser-based optical operation method, comprising a first operation method in an ellipsometry mode, wherein the first operation method comprises:

generating a first laser pulse train having a first predetermined light intensity;
periodically modulating the first laser pulse train based on a first modulation signal, so as to obtain a modulated first laser pulse train, wherein a modulation frequency of the first modulation signal is less than one quarter of a laser pulse repetition frequency;

at least using a polarizer to polarize the modulated first laser pulse train, and making the modulated first laser pulse train, which has been polarized, incident on a sample;

at least using an analyzer to analyze an optical signal reflected or diffracted from the sample to obtain a processed optical signal;

using a first detector to detect the processed optical signal and output a corresponding first detection signal;

performing lock-in amplification on the first detection signal to generate a noise-processed first detection signal on the basis that the first modulation signal is used as a reference signal; and

obtaining information related to characteristics of the sample based on the noise-processed first detection signal;

wherein the modulation frequency of the first modulation signal is greater than a signal acquisition frequency of the first detector.

19. The method according to claim 18, wherein the optical operation
5 method further comprises a second operation method in a pulse cleaning mode,
wherein the second operation method comprises:

generating a second laser pulse train having a second predetermined light
intensity;

modulating the second laser pulse train using a second modulation signal to
10 obtain a modulated second laser pulse train; and

making the modulated second laser pulse train incident on the sample, so as to
clean an airborne molecular contamination layer on a surface of the sample.

20. The method according to claim 19, further comprising: operatively
15 selecting one of the ellipsometry mode and the pulse cleaning mode.

21. The method according to claim 20, wherein operatively selecting one
of the ellipsometry mode and the pulse cleaning mode comprises:

adjusting a light intensity controller to control a light intensity of a laser pulse
20 train generated from a pulsed laser.

22. The method according to claim 19, further comprising:

optically splitting the modulated first laser pulse train, which has been
polarized, to generate reference light;

25 detecting the reference light to output a second detection signal; and

performing lock-in amplification on the second detection signal to generate a
noise-processed second detection signal on the basis that the first modulation signal
is used as a reference signal; and

correcting the noise-processed first detection signal based on the noise-
30 processed second detection signal.

23. The method according to claim 20, wherein

at least using a polarizer to polarize the modulated first laser pulse train
comprises: using a first phase compensator to generate a phase delay between two

polarization components of the modulated first laser pulse train that has been polarized, and rotating one of the polarizer and the first phase compensator during the detection by the first detector; or

- 5 at least using an analyzer to analyze an optical signal reflected or diffracted from the sample comprises: using a second phase compensator to generate a phase delay between two polarization components of the optical signal, and rotating one of the analyzer and the second phase compensator during the detection by the first detector.