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Description

Apparatus and method for detecting an amount of depolarization of a linearly polarized beam

The present invention relates to an apparatus and a method for detecting an amount of depolarization of a linearly polarized beam transmitted by a birefringent medium.

This apparatus and method, respectively, can conveniently be used for detecting internal stress fields inherent to a semiconductor wafer which normally is isotropic and, thus, does not exhibit any birefringence. As the internal stress fields are induced by dislocations and slip lines, the detection result will be a measure for the amount of dislocations and slip lines and, thus, will be a measure of the quality of the wafer and the resulting semiconductor devices. The linearly polarized beam is preferably transmitted by the birefringent medium in a direction perpendicular to the surface of the birefringent medium.

Usually, the manufacture of semiconductor devices involves various steps of wafer processing and, in particular, thermal processing steps during which the wafers are mechanically stressed. As a consequence, dislocations, slides and slip lines in the crystal are generated which will for example cause leakage currents and, thus, tremendously deteriorate the device characteristics. Accordingly, it is necessary to assess the amount of dislocations and slip lines and, based on the result, reject those wafers having an amount of dislocations and slip lines which exceeds a previously determined threshold.

The degree of dislocations and slip lines can be detected by a method called Scanning Infrared Depolarization. The principle of slip line detection by Scanning Infrared Depolarization is based on the fact that linearly polarized light

transmitted by a silicon wafer splits up into two orthogonal components, parallel and perpendicular components, with respect to the incident light when internal stress fields lower the symmetry of the crystal from tetrahedral to tetragonal or even lower.

Stated differently, a normally isotropic silicon wafer becomes birefringent when internal stress fields ocurr. Accordingly, the two orthogonal components form the ordinary and extraordingary beams, respectively, are transmitted with different velocities. As a consequence, the beam emerging from the wafer is elliptically polarized due to the phase difference between the two orthogonal components.

The stress fields occurring in a semiconductor wafer are caused by the distortion of the crystal by dislocations or slip lines. The ratio between the two orthogonal components gives a good measure of the strength of the stress field. An experimental setup for a Scanning Infrared Depolarization measurement is shown in Figure 2. In Figure 2, reference numeral 1 denotes a linearly polarized laser beam emitted by a laser device (not shown). Reference numeral 2 denotes the laser beam after it has been transmitted by the semiconductor wafer 5. Reference numeral 7 is a polarization beam splitter which splits the incoming beam 2 into the orthogonal components 3 and 4. Component 3 is detected by photodetector 8, and component 4 is detected by photodetector 9. The slip line is represented as a step denoted by reference numeral 6.

The effect described above is very weak. Accordingly, the ratio of the vertical component to the parallel component of the light beam is 1: 100 or even less. In order to detect the weak vertical signal, the amplifier amplifying the photo diode signal has to operate at a very high gain.

However, the perpendicular component detected by the detector is not only caused by the depolarization induced by slip

lines but it is also caused by scattering of light. Due to the imperfectness of the wafer surface such as surface roughness or impurities, the polarized light is scattered. In particular, patterns from the semiconductor device such as trenches and other structures will cause light scattering. As a consequence, the polarized light will change its polarization direction or will even become unpolarized.

The momentary parallel and perpendicular components of this scattered light will then be detected by both detectors. If the amount of scattered light exceeds the true signal by magnitudes, as it is in particular the case when the wafers are already patterned, the amplifiers start to work nonlinear or are driven into saturation. In both cases the amplifiers become blind for the weak signal representing the true depolarization effect.

The difficulties arising during a scanning infrared depolarization measurement can partially be avoided when the measurement is performed before structures such as trenches which will largely cause light scattering are patterned. However, since during the trench formation also heat processing steps are performed, the amount of dislocations and slip lines will still increase during and after the trench formation. Accordingly, a measurement before the trench formation will cause false measurement results.

Moreover, such a measurement will avoid scattering due to trenches. However, scattering due to impurities or surface roughness cannot be suppressed.

It is therefore an object of the present invention to provide an improved apparatus and an improved method, respectively, for detecting an amount of depolarization of a linearly polarized beam.

Moreover, it is an object of the present invention to provide an improved apparatus and an improved method, respectively, for determining an internal stress field in a semiconductor wafer.

According to the present invention, the above object is achieved by an apparatus for detecting an amount of depolarization of a linearly polarized beam transmitted by a birefringent medium, comprising:
a first beam splitter for separating a first portion of said transmitted beam into orthogonal components;
a first set of at least two photodetectors for detecting a respective one of the orthogonal components separated by said first beam splitter;
a second beam splitter for separating a second portion of said transmitted beam into orthogonal components, wherein said second beam splitter is disposed off-axis of the incident linearly polarized beam;
a second set of at least two photodetectors for detecting a respective one of the orthogonal components separated by said second beam splitter; and
a subtracting device for subtracting the signals received by said second set of photodetectors from the respective signals received by said first set of photodetectors.

Moreover, the above object is achieved by a method for detecting an amount of depolarization of a linearly polarized beam transmitted by a birefringent medium, comprising the steps of:
separating a first portion of said transmitted beam into orthogonal components by means of a first beam splitter;
detecting the orthogonal components separated by said first beam splitter by means of a first set of photodetectors;
separating a second portion of said transmitted beam into orthogonal components by means of a second beam splitter, wherein said second beam splitter is disposed off-axis of the incident linearly polarized beam;

detecting the orthogonal components separated by said second beam splitter by means of a second set of photodetectors; and subtracting the signals received by said second set of photodetectors from the respective signals received by said first set of photodetectors.

Preferably, the linearly polarized beam is transmitted in a direction perpendicular to the surface of the birefringent medium and wherein the first portion of said transmitted beam is an on-axis portion and the second portion of said transmitted beam is an off-axis portion.

In addition, the present invention provides an apparatus for determining an internal stress field in a semiconductor device comprising a laser device emitting a linearly polarized infrared laser beam and an apparatus for detecting an amount of depolarization of said linearly polarized infrared laser beam after said laser beam has been transmitted by said semiconductor wafer, wherein said apparatus for detecting an amount of depolarization of said linearly polarized laser beam is as defined above.

Furthermore, the present invention provides a method for determining an internal stress field in a semiconductor wafer comprising the step of irradiating a linearly polarized infrared laser beam into said normally isotropic medium and the method of detecting an amount of depolarization of said linearly polarized laser beam after said infrared laser beam has been transmitted by said semiconductor wafer wherein said method of detecting an amount of depolarization of said linearly polarized laser beam is as defined above.

The present invention is based upon the understanding that since the effect of light scattering cannot be suppressed nor it can be avoided that the scattered light will enter the photo detectors, this portion of light has to be subtracted

from the true signal representing the depolarization due to internal stress before it enters the amplifier.

In the following, the present invention will be described in detail with reference to the accompanying drawings.

Figure 1 shows an experimental setup of the apparatus of the present invention; and

Figure 2 shows an experimental setup of the apparatus used in the prior art.

In Figure 1, a linearly polarized laser beam having a wavelength of around 800 to 900 nm and a beam diameter of 200 nm is emitted by a laser device 19, for example a GaAs laser diode. The laser beam is transmitted by a semiconductor wafer 5. The transmitted laser beam 2 now is elliptically polarized, and it is split by the beam splitter 7 into two orthogonal components 3 and 4. Component 3 is detected by photodetector 8, and component 4 is detected by photodetector 9. In order to separate the orthogonal components, the beam splitter 7 is either implemented as a polarization beam splitter or the beam splitter 7 is polarization independent, and the two components 3 and 4 are polarized by a set of orthogonal polarizers, respectively. In the present case, the incidence direction of the laser beam 1 corresponds to the optical axis of the semiconductor wafer 5. The laser beam is directed perpendicular to the surface of the semiconductor wafer.

In addition, a second beam splitter 12 for separating two orthogonal components 15, 16 is positioned a few degrees off-axis so as to separate an off-axis portion 11 of the transmitted laser beam. Moreover, a second set of photodetectors 13, 14 is positioned so that photodetector 13 detects component 15, and photodetector 14 detects component 16.

The off-axis portion 11 of the transmitted laser beam has been scattered by surface roughness, particles or, in particular, device patterns. Since in the off-axis direction only the scattered light will be detected, there is now one set of detectors sensitive on both the scattered light as well as the true signal, while one set of detectors is sensitive on the scattered light only. More concretely, the set of detectors 8, 9 detecting the on-axis portion of the transmitted light is sensitive on the scattered light as well as the signal, while the set of detectors 13, 14 detecting the off-axis portion of the transmitted light, is sensitive on the scattered light only.

Reference numeral 17 denotes a subtracting device for subtracting the signals of both sets of detectors resulting in the required true depolarization signal. In particular, the subtracting device subtracts the signal representing the off-axis parallel component from the signal representing the on-axis parallel component. Moreover, the subtracting device subtracts the signal representing the off-axis vertical component from the signal representing the on-axis vertical component. Reference numeral 18 denotes a high gain amplifier which amplifies the resulting difference signals with high gain. The ratio of the vertical component to the parallel component will then be a measure for the internal stress in the wafer and, thus, enable a quality evaluation of the wafers.

According to the present invention, by arranging a second beam splitter as well as a second set of photodetectors a few degrees off-axis, the true depolarization signal can be gained and the scattering light effect is largely suppressed. In particular, scattering items such as impurities, surface roughness and especially device structures such as trenches will no longer impede an exact depolarization measurement. Consequently, it is possible to conduct the Scanning Infrared Depolarization measurement after defining device structures

such as trenches. Thus, this measurement will be more exact and substantial than the usually performed measurements before patterning the device structures. Moreover, the effect of impurities and surface roughness can now advantageously be suppressed. As a consequence, quality evaluation can be performed at much higher precision.

In order to ensure the laser beam to be transmitted by the semiconductor wafer, its wavelength has to be appropriately chosen. In particular, an infrared laser beam emitted by a semiconductor laser such as a GaAs laser is normally used.

Usually, an experimental setup is chosen in which the laser device is fixed beneath the semiconductor wafer while the detectors as well as the beam splitters are fixed above the semiconductor wafer. The semiconductor wafer is rotated and laterally shifted so that the entire semiconductor wafer is scanned.

When determining the off-axis angle of the second beam splitter, it has to be born in mind that the scattering angle of light is not isotropic but rather lobar. Accordingly, in order to detect the portion of the scattered light which is also included in the on-axis portion, it is necessary that the displacement angle of the second beam splitter with respect to the optical axis to the semiconductor wafer be very low. However, a minimum angle is determined by the geometric arrangement of the apparatus. The present inventors found out that an angle of 3° to 5° will provide optimum results.

The accuracy of the measurement as described above can be remarkably improved by using a lock-in amplifier. In this case the laser beam irradiated into the semiconductor wafer is chopped with a predetermined frequency. The lock-in amplifier will then only take into account those signals from the two sets of detectors which signals have this predetermined frequency. The lock-in amplifier subtracts the signal supplied

by the set of off-axis detectors from the respective signals supplied by the set of on-axis detectors.

The present invention is in particular useful when wafers having highly scattering surfaces or various wafer topographies have to be examined.

Although the present invention has been explained with respect to the examination of semiconductor wafers, it is apparent to those skilled in the art that it can be applied to any kind of birefringent materials, in particular normally isotropic media, having rough and highly scattering surfaces.

1 Incident laser beam
2 transmitted on-axis laser beam
3 on-axis vertical component
4 on-axis parallel component
5 semiconductor wafer
6 slip line
7 first beam splitter
8 first photodetector for the vertical component
9 first photodetector for the parallel component
10 trenches
11 off-axis portion of the laser beam
12 second beam splitter
13 second photodetector for the parallel component
14 second photodetector for the vertical component
15 off-axis parallel component
16 off-axis vertical component
17 subtracting device
18 high gain amplifier
19 infrared laser device

Claims

1. An apparatus for detecting an amount of depolarization of a linearly polarized beam (1) transmitted by a birefringent medium (5), comprising:
a first beam splitter (7) for separating a first portion (2) of said transmitted beam into orthogonal components (3, 4);
a first set of at least two photodetectors (8, 9) for detecting a respective one of the orthogonal components (3, 4) separated by said first beam splitter (7);
a second beam splitter (12) for separating a second portion (11) of said transmitted beam into orthogonal components (15, 16), wherein said second beam splitter (12) is disposed off-axis of the incident linearly polarized beam (1);
a second set of at least two photodetectors (13, 14) for detecting a respective one of the orthogonal components (15, 16) separated by said second beam splitter (12); and
a subtracting device (17) for subtracting the signals received by said second set of photodetectors (13, 14) from the respective signals received by said first set of photodetectors (8, 9).

2. The apparatus according to claim 1, wherein the linearly polarized beam (1) is transmitted in a direction perpendicular to the surface of the birefringent medium (5) and wherein the first portion (2) of said transmitted beam is an on-axis portion and the second portion (11) of said transmitted beam is an off-axis portion.

3. The apparatus for detecting an amount of depolarization of a linearly polarized beam according to claim 1 or 2, wherein said second beam splitter (12) is disposed at an angle of 3° to 5° off-axis.

4. The apparatus for detecting an amount of depolarization of a linearly polarized beam according to any of claims 1 to 3,

further comprising an amplifier (18), to which the signal of said subtracting device is supplied.

5. The apparatus for detecting an amount of depolarization of a linearly polarized beam according to any of claims 1 to 3, wherein said subtracting device (17) is a lock-in amplifier.

6. An apparatus for determining an internal stress field in a semiconductor wafer (5) comprising a laser device (19) emitting a linearly polarized infrared laser beam (1) and an apparatus for detecting an amount of depolarization of said linearly polarized infrared laser beam after said laser beam (1) has been transmitted by said semiconductor wafer (5), wherein said apparatus for detecting an amount of depolarization of said linearly polarized laser beam is as defined in any of claims 1 to 5.

7. A method for detecting an amount of depolarization of a linearly polarized beam (1) transmitted by a birefringent medium (5), comprising the steps of:
separating a first portion (2) of said transmitted beam into orthogonal components by means of a first beam splitter (7);
detecting the orthogonal components (3, 4) separated by said first beam splitter (7) by means of a first set of photodetectors (8, 9);
separating a second portion (11) of said transmitted beam into orthogonal components (15, 16) by means of a second beam splitter (12), wherein said second beam splitter (12) is disposed off-axis of the incident linearly polarized beam (1);
detecting the orthogonal components (15, 16) separated by said second beam splitter (12) by means of a second set of photodetectors (13, 14); and
subtracting the signals received by said second set of photodetectors (13, 14) from the respective signals received by said first set of photodetectors (8, 9).

8. The method for detecting an amount of depolarization of a linearly polarized beam according to claim 7 wherein the linearly polarized beam (1) is transmitted in a direction perpendicular to the surface of the birefringent medium (5) and wherein the first portion (2) of said transmitted beam is an on-axis portion and the second portion (11) of said transmitted beam is an off-axis portion.

9. A method for detecting an amount of depolarization of a linearly polarized beam according to claim 7 or 8, further comprising the step of amplifying the signal which results from the step of subtracting.

10. A method for determining an internal stress field in a semiconductor wafer (5) comprising the step of irradiating a linearly polarized infrared laser beam (1) into said semiconductor wafer (5) and the method of detecting an amount of depolarization of said laser beam after said linearly polarized laser beam (1) has been transmitted by said semiconductor wafer (5) wherein said method of detecting an amount of depolarization of said linearly polarized laser beam is as defined in any of claims 7 to 9.