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Combined ocd and photoreflectance method and system

Abstract

A combined OCD and photoreflectance system and method for improving the OCD performance in measurements of optical properties of a target sample. The system comprises (a) either a single channel OCD set-up comprised of a single probe beam configured in a direction normal/oblique to the target sample or a multi-channel OCD set-up having multiple probe beams configured in normal and oblique directions to the target sample for measuring the optical properties of the target sample, (b) at least one laser source for producing at least one laser beam, (c) at least one modulation device to turn the at least one laser beam into at least one alternatingly modulated laser beam, and (d) at least one spectrometer for measuring spectral components of the at least one light beam reflecting off said target sample; wherein the at least one alternatingly modulated laser beam is alternatingly modulating the spectral reflectivity of the target sample.

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Background/Summary

FIELD OF THE INVENTION

(1) The present invention relates to semiconductor measurement techniques. More specifically, the present invention relates to semiconductor metrology techniques for measurement of device critical dimensions by optical means.

BACKGROUND OF THE INVENTION

(2) OCD (Optical Critical Dimension) is a subset of semiconductor metrology techniques for in-line measurement of device critical dimensions by optical spectroscopic methods (most commonly Spectral Ellipsometry or Spectral Reflectometry).

(3) Since relevant dimensions of semiconductor devices are well below the diffraction limit of UV-Visible light, optical microscopy can't directly measure them. Instead, OCD is a model-based technique which works in the following way: Spectra of the structure to be analyzed are measured (preferably at multiple angles of incidence, polarizations etc.); A parametrized geometric model is built with enough degrees of freedom to closely represent the structure; Theoretical spectra based on that model are calculated using detailed electromagnetic simulation; and The model parameters are iteratively altered until best match is obtained between the theoretical and measured spectra.

(4) For many years, OCD has been the workhorse of semiconductor fab inline metrology due to advantages thereof over other techniques—it is fast, non-destructive, non-contact and does not require a vacuum or any other special treatment of the sample. It's main weakness, however, lies in its indirect nature—the results can be affected by uncertainties in the model fidelity, calculation errors, optical system parameters, and material optical properties. Some of these concerns can be mitigated by improvements in hardware and software, but some are more fundamental.

(5) The calculation of a theoretical spectrum from model parameters is commonly accomplished through standard electromagnetic modeling engines (such as Rigorous Coupled Wave Analysis). However, the process of interpreting the measured data to deduce the underlying structural parameters is highly challenging its eventual performance (precision, accuracy) is determined by the spectral sensitivity to the dimensional parameters of interest and the correlations between the spectral impact of variations of different parameters. Parameters with weak spectral effect, or parameters for which this effect is highly similar to the changes induced by variations of other parameters, would suffer from poor interpretation performance.

(6) Such issues are increasingly plaguing OCD in direct correlation to the shrinking dimensions and increasing geometric and material complexity encountered in advanced semiconductor technology nodes.

(7) One class of such problems is related to optical contrast—adjacent parts of the structure which are made of different, but optically similar, materials. As an illustration, consider for example a thin film of low Ge concentration Silicon-Germanium over Silicon. The two materials can have very different physical (e.g. electrical) properties while having quite similar optical permittivity. The spectrum will then be weakly sensitive to the film thickness, essentially seeing both materials as the same.

(8) As another very common example, characterization of an ultra-thin film deposited over some complicated structure is needed. It is commonly extremely difficult to separate out the weak spectral sensitivity to this layer, from the (significantly stronger) influences of other dimensional parameters.

(9) It is, therefore, an aim of the present invention to provide a system and method for in-line measurement of device critical dimensions. A system and method suitable to the shrinking dimensions and increasing geometric and material complexity encountered in advanced semiconductor technology nodes.

SUMMARY OF THE INVENTION

(10) The present invention provides a system and method for improving the performance of OCD in challenging applications. More specifically, the present invention provides a system and method for in-line measurement of device critical dimensions, a combined OCD and photoreflectance (PR) system and method suitable to the shrinking dimensions and increasing geometric and material complexity encountered in advanced semiconductor technology nodes. In accordance with some embodiments of the present invention, photoreflectance (PR) spectroscopy offers a unique way to selectively change the sensitivity to different materials and thus highlight some parameters or break correlations between parameters. The reason for this is two-fold: PR response is strongly material dependent. For a given pump wavelength, some materials will experience PR while others will be completely unaffected. The PR spectrum of semiconductors is usually highly localized in frequency, with sharp features located at the band structure critical point energies. This also can help with decoupling the contributions from different materials.

(11) In accordance with some embodiments of the present invention, there is thus provided a combined OCD and photoreflectance apparatus for improving the OCD performance in measurements of optical properties of a target sample.

(12) The combined OCD and photoreflectance apparatus comprising: (a) either a single channel OCD set-up comprised of a single probe beam configured in a direction normal/oblique to the target sample or a multi-channel OCD set-up having multiple probe beams configured in normal and oblique directions to the target sample for measuring the optical properties of the target sample in said normal direction and/or in said oblique direction; (b) at least one laser source for producing at least one laser beam; (c) at least one modulation device to turn the at least one laser beam into at least one alternatingly modulated laser beam, and thus, to allow said alternatingly modulated laser beam to alternatingly modulate the spectral reflectivity of the target sample, so that, a light beam reflecting off said target sample is alternatingly a “pump on” light beam and a “pump off” light beam; and (d) at least one spectrometer for measuring spectral components of the at least one light beam reflecting off said target sample; wherein said at least one light beam that is reflecting off the target sample is directed into said at least one spectrometer, and wherein said at least one alternatingly modulated laser beam is alternatingly modulating the spectral reflectivity of the target sample.

(13) Furthermore, in accordance with some embodiments of the present invention, the modulating device directly modulating the at least one laser source or in a path of said at least one laser beam to produce at least one modulated laser beam. Furthermore, in accordance with some embodiments of the present invention, the multi-channel OCD set-up is comprised of a first probe beam configured in a direction normal to the target sample and a second probe beam configured in a direction that is oblique to the target sample.

(14) Furthermore, in accordance with some embodiments of the present invention, the single/multiple probe beams) and the laser beam are directed to hit a single spot on said target sample.

(15) Furthermore, in accordance with some embodiments of the present invention, the combined OCD and photoreflectance apparatus further comprises an optical element directing a pre-determined portion of either the single probe beam or at least one of the multiple probe beams onto the target sample.

(16) Furthermore, in accordance with some embodiments of the present invention, the optical element is selected from a beam splitter and a mirror.

(17) Furthermore, in accordance with some embodiments of the present invention, the combined

OCD and photoreflectance apparatus further comprising at least one optical member for focusing either the single probe beam or at least one of the multiple probe beams onto the optical element.
(18) Furthermore, in accordance with some embodiments of the present invention, the combined OCD and photoreflectance apparatus further comprising at least one optical member for focusing either the single probe beam or at least one of the multiple probe beams onto the target sample.
(19) Furthermore, in accordance with some embodiments of the present invention, the combined OCD and photoreflectance apparatus further comprising at least one optical member for focusing either the single probe beam or at least one of the multiple probe beams onto the at least one spectrometer.
(20) Furthermore, in accordance with some embodiments of the present invention, the combined OCD and photoreflectance apparatus further comprising a combiner to combine either the single probe beam or at least one of the multiple probe beams pith the at least one alternatingly modulated laser beam into a single beam prior to hitting the target sample.
(21) Furthermore, in accordance with some embodiments of the present invention, the combined OCD and photoreflectance apparatus further comprising a notch filter/polarizer for filtering out the modulated laser beam from a combined beam reflecting off the target sample prior to entering into the spectrometer.
(22) Furthermore, in accordance with some embodiments of the present invention, the combined OCD and photoreflectance apparatus further comprises an optical element directing a pre-determined portion of the combined beam onto the target sample.
(23) Furthermore, in accordance with some embodiments of the present invention, the optical element is selected from a beam splitter and a mirror.
(24) Furthermore, in accordance with some embodiments of the present invention, the combined OCD and photoreflectance apparatus further comprising at least one optical member for focusing the combined beam onto the optical element.
(25) Furthermore, in accordance with some embodiments of the present invention, the combined OCD and photoreflectance apparatus further comprising at least one optical member for focusing the combined beam onto the target sample.
(26) Furthermore, in accordance with some embodiments of the present invention, the combined OCD and photoreflectance apparatus further comprising at least one optical member for focusing the combined beam into the notch filter/polarizer.
(27) Furthermore, in accordance with some embodiments of the present invention, there is thus provided a combined OCD and photoreflectance system for improving the OCD performance in measurements of optical properties of a target sample and for calculating light-induced change in optical properties of a target sample. The combined OCD and photoreflectance system comprising the above-described combined OCD and photoreflectance apparatus wherein the combined OCD and photoreflectance apparatus converting said “pump on” light beam and said “pump off” light beam to a “pump on” signal and a “pump off” signal and transferring said “pump on” signal and said “pump off” signal to a computer for subtracting the “pump on” signal corresponding to a spectrum (R) from the “pump off” signal corresponding spectrum (R+ΔR) to get a PR signal ΔR.
(28) Furthermore, in accordance with some embodiments of the present invention, there is thus provided a combined OCD and photoreflectance method for measuring and calculating light-induced change in optical properties of a target sample. The method comprising: (a) providing the above-described combined OCD and photoreflectance system; (b) either focusing a single/multiple probe beam(s) in a direction normal and/or oblique to a spot on a target sample and a laser beam that is alternatingly modulated onto said spot on the target sample or focusing a combined beam comprised of a probe beam and a laser beam that is alternatingly modulated to a spot on said target sample; (c) hitting said spot on the target sample either via said single/multiple probe beam(s) and said laser beam that is alternatingly modulated or via said combined beam to alternatingly modulate the reflectivity of the target sample, thus, to have “pump-on” light beam and “pump off” light beam

alternatingly reflecting off the target sample; (d) directing either a single/multiple light beam(s) or a combined beam comprised of a probe beam and a modulated laser beam reflecting off the target sample to at least one spectrometer; (e) filtering out the modulated laser beam from the combined beam reflecting off the target sample prior to reaching the at least one spectrometer; (f) converting the “pump on” light beam and the “pump off” light beam into a “pump on” signal and a “pump off signal and transferring the “pump on” signal and the “pump off signal to a computer; and (g) subtracting the “pump on” signal corresponding to a spectrum (R) from the “pump off” signal corresponding to a spectrum (R+ΔR) to get a PR signal ΔR.
(29) Furthermore, in accordance with some embodiments of the present invention, the combined OCD and photoreflectance method further comprising synchronizing the at least one spectrometer with a modulation device when using said combined beam.

Description

BRIEF DESCRIPTION OF THE FIGURES
(1) FIG. **1** is an example of PR spectrum of Silicon from 320 nm to 400 nm.
(2) FIG. **2** (PRIOR ART) illustrates an SR OCD apparatus having a normal incidence channel for measuring optical properties of a target sample.
(3) FIG. **3** (PRIOR ART) illustrates a multichannel OCD apparatus having a normal and oblique incidence channels for measuring optical properties of a target sample.
(4) FIG. **4** illustrates a combined OCD and Photoreflectance (PR) spectroscopy apparatus in accordance with some embodiments of the present invention.
(5) FIG. **5** illustrates an alternative combined OCD and Photoreflectance (PR) spectroscopy apparatus in accordance with some embodiments of the present invention.
(6) FIG. **6** illustrates a combined OCD set-up and Photoreflectance (PR) spectroscopy apparatus for measuring optical properties of a target sample via a first probe beam configured in a direction normal to the target sample and a second probe beam configured at an oblique angle of incidence onto the target sample in accordance with some embodiments of the present invention.
(7) FIG. **7** illustrates a method for measuring optical properties of a target sample via a combined OCD and photoreflectance system in accordance with some embodiments of the present invention.
DETAILED DESCRIPTION OF THE FIGURES
(8) FIG. **1** is an Example of PR spectrum of Silicon from 320 nm to 400 nm.
(9) In accordance with some embodiments of the present invention, it would seem beneficial to have a PR measurement channel working in conjunction with standard OCD, measuring the target sample at the same time and location so as to provide complementary spectral information. This information can be used in several ways: Model-based—by including a theoretical model of the PR response into the spectrum calculation. Such modeling can include account for the multiple related effects, such as thermos-reflectance, electro-reflectance, magneto-reflectance, and even such considerations as charge carrier excitation and diffusion, band structure and photo-effects on the band structure, nonlinear responses etc. In certain simple cases like thin films, the response at specific wavelengths can be directly correlated to film thickness, absorption or refractive index.
(10) In more complicated cases, Machine Learning algorithms trained on controlled reference data can be employed, and would benefit from the increased sensitivities of PR.
(11) The appeal of this approach also comes from the synergy between the two methods. The broadband spectroscopic measurement channel of an OCD tool is suited to serve as the probe in a PR system. To complete the system, a modulated pump beam needs to be inserted into the optical path and synchronized to the spectral acquisition electronics.
(12) However, some details need to be considered for this to work. One such is the question of noise. One of the challenges of PR is the small relative modulation of the reflectance

(ΔR/R˜10.sup.−4−10.sup.−5) which requires reflectometry measurement at very high signal-to-noise ratios (SNRs) of the order of ˜10.sup.5-6. This is especially true in the context of integration with OCD systems which usually have SNR on the order of ˜10.sup.3-4 and are required to measure at less than ˜1 second to maintain reasonable throughput. If PR is to be part of the OCD measurement, it also should conform to similar requirements.
(13) A possible way to address this problem without completely redesigning the OCD system is to use a high brightness source such as a supercontinuum laser (SCL) or some types of laser-driven plasma sources.
(14) As an illustration of typical numbers, achieving a shot noise limited SNR of 10.sup.5 requires each pixel in the sensor to accumulate>10.sup.10 photoelectrons (i.e., ˜10.sup.3-4 times more light than a typical OCD measurement, at a similar acquisition time). To achieve this in a span of 1 s, the product of frame rate to full well capacity (FWC) is ˜10.sup.10e.sup.−/s.
(15) Practical values based on current sensor and electronics technology are frame rates of ˜10.sup.2-3 PPS and FWC of ˜10.sup.7-8e.sup.−, which are achievable with linear array CCDs. By combining this sort of acquisition system with a high brightness source such as a SCL, the SNR and throughput requirements can be met.
(16) Another issue in PR spectroscopy is contamination of the probe beam by the much brighter pump beam, either directly or through stray light. In this context, a key parameter of OCD tool design is the number of angles of incidence (AOIs), which mostly come in two flavors: Normal Incidence channel: usually found in integrated metrology tools that need to have a small footprint. Single objective lens serves both illumination and collection. Multichannel (Normal and Oblique Incidence channels): usually found in stand-alone metrology tools. Separate objectives are used for the oblique illumination and collection of the reflected beam.
(17) Bringing the pump and probe beam together on the target sample can be implemented in several ways depending on the system design: Noncolinear: The most straightforward way to separate the pump and probe beams is by using different AOIs, geometrically separating them at the detector plane as illustrated below in FIG. **4**. This requires focus and boresight matching of the two beams. In multichannel tools, this can be achieved by using one of the channels (normal or oblique) for the pump and the other for the probe beams. Alternatively, the pump light can be inserted obliquely from outside the objective in a normal-only design. This however requires a more substantial modification of the system to accommodate. Another option is to use a normal channel with large-NA objective, and illuminate only the central part of the entrance pupil by the probe beam and the outer ring by the pump, allowing them to be easily separated in the collection channel by using suitable apertures. Colinear: Combining the pump and probe into a co-linear beam as illustrated in FIGS. **5** & **6** below has some advantages, such as removing the need for focus and boresight alignment of the two channels. This however requires that they be separated in some other way, such as: Polarization: The pump and probe beams can be orthogonally polarized such that a polarized in the collection channel will block the pump beam from reaching the detector. Spectrally: If the pump WL is sufficiently far from the region of interest in the probe spectrum, it can be separated by a dispersive element in the spectrometer or before it, or if the pump wavelength resides outside the measured spectral range it would not be directly detected. Temporally: The probe beam can itself be modulated at a different frequency, so that the PR signal is recovered by LID at the sum frequency of the pump and probe modulation while rejecting both the pump itself and other artifacts associated with such as Photoluminescence.
(18) The pump beam can be chosen or controlled so as to alter performance, in several ways: Wavelength: different wavelengths will affect materials differently according to their band structure and occupancy levels, allowing selective enhancement of sensitivity to different materials in the structure. Intensity: PR is generally non-linear, since the generated charge carriers affect the band structure which in turn changes the absorption of more photons. By changing the pump beam intensity, these non-linear properties can be probed, providing information on (e.g.) charge carrier

lifetime, charge traps and defects. Polarization: Changing pump polarization can change the absorption profile of the pump beam, highlighting different parts of the structure. Repetition rate and illumination spot: Since charge carriers are mobile, they diffuse away from the pump spot in a way governed by their lifetime, mean free path, effective mass etc. Changing the temporal and spatial pattern of the pump illumination will affect the PR response in a way that can be linked to these physical parameters. In addition, as soon as the repetition rate becomes comparable with the excited charge carriers' lifetime, the PR signal can strongly depend on the specific repetition rate.
(19) Of course, a proper choice of the ‘probe’ path properties (wavelength range, polarizations, AOI etc.) would dictate the metrological benefit of this scheme—the parameter sensitivities, correlations and overall performance.
(20) FIG. **2** (PRIOR ART) illustrates an SR OCD apparatus **200** having a normal incidence channel for measuring optical properties of a target sample. In accordance with some embodiments of the present invention, the OCD apparatus **200** is used for measuring optical properties of a target sample **208** via a probe beam **204** configured in a direction normal to the target sample **208**. The OCD apparatus **200** comprises a probe source **202** for producing a probe beam **204**, and a spectrometer **206** for measuring the spectral components of a beam reflected from a target sample **208**. The OCD apparatus **200** further comprises an optical element **210** such as a beam splitter, a mirror and the like and multiple lenses, e.g., lens **212**, lens **214** and lens **216**.
(21) The optical element **210** directing the probe beam **204** onto the target sample **208** and directing the beam reflecting off the target sample **208** to the spectrometer **206**.
(22) In accordance with some embodiments of the present invention, lens **212** focuses the probe beam **204** to the optical element **210**, lens **214** is a single objective lens serving both illumination and collection as it focuses the beam exiting the optical element **210** to the target sample **208** and the beam reflecting off the target sample **208** to the optical element **210**, and lens **216** focuses the beam exiting the optical element **210** to the spectrometer **206**.
(23) Thus, while in operation, the probe source **202** generates a continuous probe beam **204** which is focused via lens **212** onto optical element **210**. Optical element **210** directs a pre-determined portion of the probe beam **204** onto the target sample **208** via lens **214**, the beam reflecting off the target sample **208** is focused via lens **214** onto the optical element **210** and the beam exiting the optical element **210**, is focused via the lens **216** into the spectrometer **206**.
(24) Thus, while in operation, the probe source **202** generates a continuous probe beam **204** which is focused via lens **212** onto optical element **210**. Optical element **210** directs a pre-determined portion of the probe beam **204** onto the target sample **208**, and the beam reflecting off the target sample **208** is focused onto the optical element **210** via the lens **214** and into the spectrometer **206** via lens **216**.
(25) FIG. **3** (PRIOR ART) illustrates a multichannel OCD apparatus **300** having a normal and oblique incidence channels for measuring optical properties of a sample.
(26) In accordance with some embodiments of the present invention, the multichannel OCD apparatus **300** comprises a first probe beam **302** configured in a direction normal to the target sample **330** and a second probe beam **306** configured at an oblique angle of incidence onto the target sample **330** for measuring optical properties of a sample via a combined OCD and photoreflectance system in accordance with some embodiments of the present invention.
(27) In accordance with some embodiments of the present invention, separate objectives are used for the oblique illumination and collection of the reflected beam.
(28) The OCD apparatus **300** further comprises a first spectrometer **310** and a second spectrometer **312** for measuring the spectral components of beams reflected from the target sample **330**, an optical element **314** such as a beam splitter, a mirror and the like and multiple focusing members such as lens **316**, lens **318**, lens **320**, lens **322**, lens **324**, lens **326** and lens **328**.
(29) As seen in the figure, the optical element **314** directing the probe beam **304** in a direction normal to the target sample **330** and directing the beam reflecting off the target sample **330** to the

first spectrometer **310**, and lens **316** focuses the probe beam **304** to the optical element **314**, lens **320** focuses the beam exiting the optical element **314** to the first spectrometer **310**, and lens **318** is a single objective lens serving both illumination and collection as it focuses the beam exiting the optical element **314** to the target sample **330** and the beam reflecting off the target sample **313** to the optical element **314**.

(30) The second probe source **306** produces a second probe beam **308** which is directed at an oblique angle of incidence onto the target sample **330**. The second probe beam **308** is focused onto the target sample **330** via lenses **322** and **324**, and the beam reflected from the sample **330** is focused via lenses **326** and **328** onto the second spectrometer **312**.

(31) Thus, while in operation, the first probe source **302** and the second probe source **306** generate continuous probe beams **304** and **308** continuously. Probe beam **304** is focused via lens **316** onto optical element **314**. Optical element **314** directs a pre-determined portion of the probe beam **304** in a direction normal to the target sample **330**, and the beam reflecting off the target sample **330** is focused onto the optical element **314** via the lens **318** and into the first spectrometer **210** via lens **320**.

(32) The second probe beam **308** is directed at an oblique angle of incidence onto the target sample **330**. The second probe beam **308** is focused onto the target sample **330** via lenses **322** and **324**, and the beam reflected from the target sample **330** is focused via lenses **326** and **328** onto the second spectrometer **312**.

(33) As the spectral reflectivity of a material is closely related to electronic properties such as band structure, density of states, free carries etc., modulation spectroscopy (MS) is uniquely sensitive to these properties more than any other optical spectroscopy method. This can be of high value when electrical testing of semiconductor devices needs to be done at the early stages of their fabrication process, where conventional E-testing s impossible.

(34) The following figures illustrate combined OCD and photoreflectance (PR) systems suitable to the shrinking dimensions and increasing geometric and material complexity encountered in advanced semiconductor technology nodes in accordance with some embodiments of the present invention.

(35) FIG. **4** illustrates a combined OCD and Photoreflectance (PR) spectroscopy apparatus **400** in accordance with some embodiments of the present invention.

(36) The OCD set up comprises a probe source **402** for producing a probe beam **404**, and a spectrometer **406** for measuring the spectral components of a beam reflecting off a target sample **407**. The OCD set up further comprises an optical element **408** such as a beam splitter, a mirror and the like and focusing members such as lens **410**, lens **412** and lens **414** for focusing the probe beam **404** to the optical element **408**, for focusing the beam exiting the optical element **408** to the target sample **407**, and the beam reflecting off the target sample **407** to the spectrometer **406** respectively. Lens **412** is a single objective lens serving both illumination and collection as it focuses the beam exiting the optical element **408** to the target sample **407** and the beam reflecting off the target sample **407** to the optical element **408**.

(37) In accordance with some embodiments of the present invention, the Photoreflectance (PR) spectroscopy set up comprises a pump laser **418**, a modulator **420** in the path of the laser beam **422** and at least one optical member such as lens **424** and lens **426** for focusing the modulated laser beam **428** onto the target sample **407**.

(38) In accordance with some embodiments of the present invention, the laser beam **422** is modulated in order to alternatingly modulate the reflectivity of the sample **407** and thus to have a “pump on” light beam and a “pump off” light beam reflecting off the sample **407**.

(39) In accordance with some embodiments of the present invention, the laser beam **422** may be attenuated electronically or via appropriate attenuation optical filters, e.g., mechanically shiftable into/out optical path of pump beam and/or based on electro-optical means, etc.

(40) While in operation, the probe source **402** generates a continuous probe beam **404** which is

focused via lens **410** onto optical element **408**. Optical element **408** directs a pre-determined portion of the probe beam **404** onto the target sample **407**, and the beam reflecting off the target sample **407** is focused onto the optical element **408** via the lens **412** and into the spectrometer **406** via lens **414**.
(41) In accordance with some embodiments of the present invention, the modulator **420** alternatingly directs the pump beam **422** to the target sample **407**, and thus, alternatingly modulates the reflectivity of the target sample **407**.
(42) Thus, in accordance with some embodiments of the present invention, there are two modes in measurements, one while the modulated laser beam **428** is reaching the target sample **407** and another while the modulated laser beam **428** is shuttered out.
(43) While the laser beam **422** is reaching the target sample **407**, the light beam reflecting off the target sample **407** is a “pump-on” beam, and when the laser beam **422** is shuttered out, the light beam reflecting off the target sample **407** is a “pump-off” beam.
(44) Thus, such combined OCD and Photoreflectance (PR) spectroscopy apparatus **400** allows measuring alternatingly (a) the spectral reflectivity of the target sample **407**, and (b) the modulated reflectivity of the target sample **407**, e.g., the change in spectrum rather than the spectrum itself as a response to that perturbation.
(45) FIG. **5** illustrates an alternative combined OCD and Photoreflectance (PR) spectroscopy apparatus **500** in accordance with some embodiments of the present invention.
(46) The alternative combined OCD and Photoreflectance (PR) spectroscopy apparatus **500** is more compact compared to the apparatus illustrated and described in FIG. **4**, and therefore, may be suitable for use in spaces limited in size, for instance in semiconductor manufacturing equipment such as coating devices and the like.
(47) In accordance with some embodiments of the present invention, the alternative combined OCD and Photoreflectance (PR) spectroscopy apparatus **500** is comprised of a probe source **502** for producing a probe beam **504**, and a spectrometer **506** for measuring the spectral components of a beam reflected from a target sample **507**. The alternative combined OCD and Photoreflectance (PR) spectroscopy apparatus **500** further comprises a pump laser **508**, a modulator **510** in the path of the laser beam **512**, a combiner **514**, a notch filter/polarizer **516** and electronics **518**.
(48) In accordance with some embodiments of the present invention, the laser beam **512** is modulated in order to alternatingly modulate the reflectivity of the target sample **507** and thus to have a “pump on” light beam and a “pump off” light beam reflecting off the target sample **507**.
(49) The alternative combined OCD and Photoreflectance (PR) spectroscopy system **500** further comprises an optical element **520** directing a pre-determined portion of the combined beam **522** onto the target sample **507**, and multiple optical members such as lens **524**, lens **526** and lens **528** for focusing the combined beam onto the optical element **520**, onto the target sample **507** and into the notch filter/polarizer **516** respectively.
(50) In contrast to the OCD and Photoreflectance (PR) spectroscopy system **400** of FIG. **4** which uses two separate beams, a probe beam and a pump laser beam, directed to hit a single spot on the target sample, here, the probe beam **504** and the pump laser beam **512** are combined into a single beam that is alternatingly modulated.
(51) The pump laser beam **512** is modulated via modulator **510** and the modulated laser beam **513** is combined via combiner **514** with the probe beam **504** to produce an alternatingly modulated combined beam **522**.
(52) The alternatingly modulated combined beam **522** is focused via lens **524** onto optical element **520** which directs a pre-determined portion of the alternatingly modulated combined beam **522** in a direction normal to the target sample **507**.
(53) In accordance with some embodiments of the present invention, the beam reflecting off the target sample **507** is focused via lens **526** onto the optical element **520**, and the beam **505** exiting the optical element **520** is focused via lens **528** onto notch filter/polarizer **516** prior to entering into

the spectrometer **506**.
(54) Notch filter/polarizer **516** is used for filtering out the modulated laser beam **513** from the combined beam reflecting off the target sample **507** in order to avoid damage to the spectrometer **506**.
(55) In accordance with some embodiments of the present invention, electronics **518** is used for synchronizing the modulator **510** and the spectrometer **506**.
(56) FIG. **6** illustrates a combined OCD set-up and Photoreflectance (PR) spectroscopy apparatus **600** for measuring optical properties of a target sample via a first probe beam configured in a direction normal to the target sample and a second probe beam configured at an oblique angle of incidence onto the target sample in accordance with some embodiments of the present invention.
(57) The combined OCD set-up and Photoreflectance (PR) spectroscopy apparatus **600** is comprised of the combined OCD set-up and Photoreflectance (PR) spectroscopy **500** of FIG. **5** and an additional OCD set-up with a probe beam configured at an oblique angle of incidence onto the target sample.
(58) The combined OCD and Photoreflectance (PR) spectroscopy apparatus **600** is compact and may be suitable for use in spaces of limited in size, for instance in semiconductor manufacturing equipment such as coating devices and the like.
(59) In accordance with some embodiments of the present invention, the combined OCD and Photoreflectance (PR) spectroscopy apparatus **600** is comprised of a first probe source **602** for producing a first probe beam **604**, and a first spectrometer **606** for measuring the spectral components of a beam reflecting off a target sample **607**.
(60) The combined OCD and Photoreflectance (PR) spectroscopy apparatus **600** further comprises a pump laser **608**, a modulator **610** in the path of the laser beam **612**, a combiner **614** for combining the first probe beam **604** with the modulated laser beam **613** into a combined beam **622**, electronics **618**, and a notch filter/polarizer **619**.
(61) In accordance with some embodiments of the present invention, the laser beam **612** is modulated in order to alternatingly modulate the reflectivity of the target sample **607** and thus to have a “pump on” light beam and a “pump off” light beam reflecting off the target sample **607**.
(62) In accordance with some embodiments of the present invention, electronics **618** is used for synchronizing the modulator **610** and the spectrometer **606**.
(63) The combined OCD and Photoreflectance (PR) spectroscopy apparatus **600** further comprises an optical element **620** directing a pre-determined portion of the combined beam **622** onto the target sample **607**, and multiple optical members such as lens **624**, lens **626** and lens **628** for focusing the combined beam onto the optical element **620**, onto the target sample **607** and into the notch filter/polarizer respectively **619** prior to entering into the first spectrometer **606**.
(64) As in the OCD and Photoreflectance (PR) spectroscopy apparatus **500** of FIG. **5**, the probe beam **604** and the modulated laser beam **613** are combined into a single, combined beam **622** that is alternatingly modulated.
(65) The alternatingly modulated combined beam **622** is focused via lens **624** onto optical element **620** which directs a pre-determined portion of the alternatingly modulated combined beam **622** in a direction normal to the target sample **607**.
(66) In accordance with some embodiments of the present invention, the beam reflecting off the target sample **607** is focused via lens **626** onto the optical element **620**, and the beam **605** exiting the optical element **620** is focused via lens **628** onto notch filter/polarizer **619** prior to entering into the spectrometer **606**.
(67) The Notch filter/polarizer **619** is used for filtering out the modulated laser beam **613** from beam **605** in order to avoid damage to the spectrometer **606**.
(68) In accordance with some embodiments of the present invention, the second probe source **630** produces a second probe beam **632** directed at an oblique angle of incidence onto the target sample **607**. The second probe beam **632** is focused onto the target sample **607** via lenses **634** and **636**, and

the beam reflecting off the target sample **607** is focused via lenses **638** and **640** onto the second spectrometer **642**.

(69) Thus, while in operation, the first probe source **602** and the second probe source **630** generate continuous probe beams **604** and **632** continuously. Probe beam **604** and a modulated laser beam **613** are combined into a combined beam **622** that is alternatingly modulated. The combined beam **622** is focused via lens **624** onto an optical element **620** which directs a pre-determined portion of the combined beam **622** in a direction normal to the target sample **607**, and the beam **603** reflecting off the target sample **607** is focused onto the optical element **620** via the lens **626**.

(70) The beam **605** exiting the optical element **620** is focused onto the notch filter/polarizer **619** via lens **628** prior to entering into the spectrometer **606**.

(71) In accordance with some embodiments of the present invention, the beam **603** reflecting off said target sample **607** is carrying some modulation due to the spectral reflectivity of the target sample **607** that is alternatingly modulated.

(72) In accordance with some embodiments of the present invention, the second probe beam **632** is directed at an oblique angle of incidence onto the target sample **607**. The second probe beam **632** is focused onto the target sample **607** via lenses **634** and **636**, and the beam reflecting off the target sample **607** is focused via lenses **638** and **640** onto the second spectrometer **642**.

(73) In accordance with some embodiments of the present invention, a photoreflectance (PR) spectroscopy system may comprise one of the photoreflectance (PR) spectroscopy apparatus **400**, the photoreflectance (PR) spectroscopy apparatus **500** and the photoreflectance (PR) spectroscopy apparatus **600** and a computer.

(74) The photoreflectance (PR) spectroscopy apparatus **400**, **500**, **600** converts the “pump on” light beam and the “pump off” light beam to a “pump on” signal and a “pump off” signal and transfers the “pump on” signal and the “pump off” signal to a computer where the “pump on” signal corresponding to a spectrum (R) is subtracted from the “pump off” signal corresponding spectrum. (R+ΔR) to get a PR signal ΔR.

(75) FIG. **7** illustrates a method **700** for measuring optical properties of a target sample via a combined OCD and photoreflectance system in accordance with some embodiments of the present invention.

(76) The method **700** comprising the following steps:

(77) Step **702**: providing one of the above-described combined OCD and photoreflectance systems of FIGS. **4-6**;

(78) Step **704**: focusing a single/multiple probe beam(s) **404**, **632** in a direction normal and/or oblique to a spot on a target sample **407**, **507**, **607** and a laser beam **428** that is alternatingly modulated onto said spot on the target sample **407**, **507**, **607**.

(79) Alternatively, focusing a combined beam **522**, **622** comprised of a probe beam **504**, **604** and a laser beam **513**, **613** that is alternatingly modulated to a spot on said target sample **407**, **507**, **607**;

(80) Step **706**: hitting a single spot on the target sample **407**, **507**, **607** via single/multiple probe beam(s) **404**, **632** and alternatingly hitting that single spot on the target sample **407**, **507**, **607** via the laser beam to alternatingly modulate the reflectivity of that spot on the target sample **407**, **507**, **607**.

(81) Alternatively, synchronizing the spectrometer **506**, **606** with the modulator **510**, **610** and hitting the target sample **507**, **607** continuously via a combined beam **522**, **622** comprised of a modulated laser beam **513**, **613** and a probe beam **504**, **604**;

(82) Step **708**: directing the single/multiple light beam(s) (corresponding to the single/multiple probe beam(s)) reflecting off the target sample **407**, **507**, **607** to at least one spectrometer **406**, **506**, **606**, **642**;

(83) Step **710**: in case a combined beam **522**, **622** comprised of a probe beam **504**, **604** and a modulated laser beam **513**, **613** is used, filtering out the modulated laser beam **513**, **613** from the beam reflecting off the target sample **507**, **607** prior to reaching the spectrometer **506**, **606**;

(84) Step **712**: converting the “pump on” light beam and the “pump off” light beam into a “pump on” signal and a “pump off signal and transferring the “pump on” signal and the “pump off signal to a computer; and
(85) Step **714**: subtracting the “pump on” signal corresponding to a spectrum (R) from the “pump off” signal corresponding to a spectrum (R+ΔR) to get a PR signal ΔR.

Claims

1. A combined OCD and photoreflectance apparatus for improving the OCD performance in measurements of optical properties of a target sample comprising: (a) either a single channel OCD set-up comprised of a continuous single probe beam configured in a direction normal/oblique to the target sample or a multichannel OCD set-up having multiple continuous probe beams configured in normal and oblique directions to the target sample for measuring the optical properties of the target sample in said normal direction and/or in said oblique direction; (b) at least one laser source for producing at least one laser beam; (c) at least one modulation device to turn the at least one laser beam into at least one alternatingly modulated laser beam, and thus, to allow said at least one alternatingly modulated laser beam to alternatingly modulate the spectral reflectivity of the target sample, so that, at least one light beam reflecting off said target sample is alternatingly a “pump on” light beam and a “pump off” light beam; and (d) at least one spectrometer for measuring spectral components of the at least one light beam reflecting off said target sample; wherein said at least one light beam that is reflecting off the target sample is directed into said at least one spectrometer, and wherein said at least one alternatingly modulated laser beam is alternatingly modulating the spectral reflectivity of the target sample; and wherein the combined OCD and photoreflectance apparatus is configured to: operate in first measurement mode for providing OCD related measurements related to spectral components of the at least one light beam reflecting off said target sample when the light beam reflecting on the sample is the “pump off” light beam, and operate in a second measurement mode providing photoreflectance related measurements related to a difference between (a) spectral components of the at least one light beam reflecting off said target sample when the light beam reflecting on the sample is the “pump off” light beam, and (b) spectral components of the at least one light beam reflecting off said target sample when the light beam reflecting on the sample is the “pump on” light beam.
2. The combined OCD and photoreflectance apparatus of claim 1, wherein said at least one modulating device directly modulating the at least one laser source or in a path of said at least one laser beam to produce at least one modulated laser beam.
3. The combined OCD and photoreflectance apparatus of claim 2, further comprises an optical element directing a pre-determined portion of either the single probe beam or at least one of the multiple probe beams onto the target sample.
4. The combined OCD and photoreflectance apparatus of claim 1, wherein the single/multiple probe beam(s) and the laser beam are directed to hit a single spot on said target sample.
5. The combined OCD and photoreflectance apparatus of claim 4, further comprises an optical element directing a pre-determined portion of either the single probe beam or at least one of the multiple probe beams onto the target sample.
6. The combined OCD and photoreflectance apparatus of claim 1, further comprises an optical element directing a pre-determined portion of either the single probe beam or at least one of the multiple probe beams onto the target sample.
7. The combined OCD and photoreflectance apparatus of claim 6, wherein said optical element is selected from a beam splitter and a mirror.
8. The combined OCD and photoreflectance apparatus of claim 1, wherein said multi-channel OCD set-up is comprised of a first probe beam configured in a direction normal to the target sample and a second probe beam configured in a direction that is oblique to the target sample.

9. The combined OCD and photoreflectance apparatus of claim 8, further comprises an optical element directing a pre-determined portion of either the single probe beam or at least one of the multiple probe beams onto the target sample.
10. A combined OCD and photoreflectance apparatus for improving the OCD performance in measurements of optical properties of a target sample comprising: (a) either a single channel OCD set-up comprised of a single probe beam configured in a direction normal/oblique to the target sample or a multichannel OCD set-up having multiple probe beams configured in normal and oblique directions to the target sample for measuring the optical properties of the target sample in said normal direction and/or in said oblique direction; (b) at least one laser source for producing at least one laser beam; (c) at least one modulation device to turn the at least one laser beam into at least one alternatingly modulated laser beam, and thus, to allow said alternatingly modulated laser beam to alternatingly modulate the spectral reflectivity of the target sample, so that, at least one light beam reflecting off said target sample is alternatingly a “pump on” light beam and a “pump off” light beam; and (d) at least one spectrometer for measuring spectral components of the at least one light beam reflecting off said target sample; wherein said at least one light beam that is reflecting off the target sample is directed into said at least one spectrometer, and wherein said at least one alternatingly modulated laser beam is alternatingly modulating the spectral reflectivity of the target sample; wherein the combined OCD and photoreflectance apparatus is configured to: operate in first measurement mode for providing OCD related measurements related to spectral components of the at least one light beam reflecting off said target sample when the light beam reflecting on the sample is the “pump off” light beam; and operate in a second measurement mode providing photoreflectance related measurements related to a difference between (a) spectral components of the at least one light beam reflecting off said target sample when the light beam reflecting on the sample is the “pump off” light beam, and (b) spectral components of the at least one light beam reflecting off said target sample when the light beam reflecting on the sample is the “pump on” light beam.
11. The combined OCD and photoreflectance apparatus of claim 10, further comprises an optical element directing a pre-determined portion of the combined beam onto the target sample.
12. The combined OCD and photoreflectance apparatus of claim 11, wherein said optical element is selected from a beam splitter and a mirror.
13. The combined OCD and photoreflectance apparatus of claim 10 further comprising a notch filter/polarizer for filtering out the modulated laser beam from a combined beam reflecting off the target sample prior to entering into the spectrometer.
14. The combined OCD and photoreflectance apparatus of claim 13, further comprises an optical element directing a pre-determined portion of the combined beam onto the target sample.
15. The combined OCD and photoreflectance apparatus of claim 14, wherein said optical element is selected from a beam splitter and a mirror.