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Rotating or Rotatable Compensator Spectroscopic Ellipsometer System Including Multiple Element Lenses

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ROTATING OR ROTATABLE COMPENSATOR SPECTROSCOPIC ELLIPSOMETER SYSTEM INCLUDING MULTIPLE ELEMENT LENSES

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Continuation-in-part of application No. 10/034,800, filed on Dec. 28, 2001, now Pat. No. 6,822,738, and a continuation-in-part of application No. 09/583,229, filed on May 30, 2000, now Pat. No. 6,804,004, and a continuation-in-part of application No. 09/162,217, filed on Sep. 29, 1998, now Pat. No. 6,034,777, and a continuation-in-part of application No. 09/033,694, filed on Mar. 3, 1998, now Pat. No. 5,963,327, and a continuation-in-part of application No. 09/144,764, filed on Aug. 31, 1998, now Pat. No. 5,969,818, and a continuation-in-part of application No. 09/419,794, filed on Oct. 11, 1999, and a continuation-in-part of application No. 09/444,764, filed on Aug. 31, 1998, application No. 10/829,620, which is a continuation-in-part of application No. 10/699,540, filed on Nov. 1, 2003, and a continuation-in-part of application No. 09/945,962, filed on Sep. 4, 2001, and a continuation-in-part of application No. 09/517,125, filed on Feb. 29, 2000, and a continuation-in-part of application No. 09/246,888, filed on Feb. 8, 1999, now Pat. No. 6,084,675, which is a continuation-in-part of application No. 08/912,211, filed on Aug. 15, 1997, now Pat. No. 5,872,630, which is a continuation-in-part of application No. 08/530,892, filed on Sep. 20, 1995, now Pat. No. 5,666,201, and a continuation-in-part of application No. 08/618,820, filed on Mar. 20, 1996, now Pat. No. 5,706,212, application No. 10/829,620, which is a continuation-in-part of application No. 09/225,118, filed on Jan. 4, 1999, now Pat. No. 6,084,074, and a continuation-in-part of application No. 09/223,822, filed on Jan. 4, 1999, now Pat. No. 6,118,537, and a continuation-in-part of application No. 09/232,257, filed on Jan. 19, 1999, now Pat. No. 6,141,102, and a continuation-in-part of application No. 09/225,371, filed on Jan. 4, 1999, now Pat. No. 6,100,981, and a continuation-in-part of application No. 09/225,076, filed on Jan. 4, 1999, now Pat. No. 5,963,325, which is a continuation-in-part of application No. 09/997,311, filed on Dec. 23, 1997, now Pat. No. 5,946,098.

Provisional application No. 60/527,638, filed on Dec. 8, 2003, provisional application No. 60/527,554, filed on Dec. 6, 2003, provisional application No. 60/094,104, filed on Jul. 24, 1998.

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2,700,918 A 2/1955 Osterberg et al.
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U.S. PATENT DOCUMENTS
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ABSTRACT

Disclosed are spectroscopic ellipsometer systems which include polarizer and analyzer elements which remain fixed in position during data acquisition, and

- at least one continuously rotating or step-wise rotatable compensator which transmits an electromagnetic beam therethrough and imposes a continuously variable or plurality of sequentially discrete polarization states on a beam of electromagnetic radiation; and
- at least one multiple element lens which also transmits the electromagnetic beam therethrough.

5 Claims, 13 Drawing Sheets
COMPARISON OF SINGLE vs. DUAL WAVEPLATE COMPENSATOR DESIGN

TWO 1/4 WAVEPLATES
ROTATED AZIMUTHAL ANGLE 45 DEGREES AT
\( \lambda_c = 266 \) & 633 nm

SINGLE WAVEPLATE
\( \lambda_c = 240 \) nm

FIG. 4
Retardance Characteristics of Waveplates used in Dual Element Compensator Design

Both, Fast Axes
- \( \phi \) 45 degrees to one another

- Single \( \lambda_c = 266 \text{ nm} \)
- Single \( \lambda_c = 633 \text{ nm} \)

FIG. 5

Present Invention Dual Element Design for \( \lambda_c = 266, 633 \text{ nm} \) & \( \phi = 45 \text{ degrees} \)

FIG. 6
FIG. 7a1

FIG. 7a2
ROTATING OR ROTATABLE COMPENSATOR SPECTROSCOPIC ELLIPSOMETER SYSTEM INCLUDING MULTIPLE ELEMENT LENSES


This application further is a Continuation-In-Part of Copending application Ser. No. 10/699,540 Filed Nov. 1, 2003 and therevia of Copending application Ser. No. 09/944, 962 Filed Sep. 4, 2001, application Ser. No. 09/517,125 Filed Feb. 29, 2000, and therevia of application Ser. No. 09/246,888 filed Feb. 8, 1999, (now U.S. Pat. No. 6,084,675). Further, via the Ser. No. 09/246,888 application, this application is a Continuation-In-Part of application Ser. No. 08/912,211 filed Aug. 15, 1997, (now U.S. Pat. No. 5,872,630), which was a CIP from application Ser. No. 08/530,892 filed Sep. 20, 1995, (now U.S. Pat. No. 5,666,201); and is a CIP of application Ser. No. 08/618,820 filed Mar. 20, 1996, (now U.S. Pat. No. 5,706,212). This application is further a CIP of application Ser. No. 09/225,118, Jan. 4, 1999 (now U.S. Pat. No. 6,084,674); Ser. No. 09/223,822, Jan. 4, 1999 (now U.S. Pat. No. 6,118,537); Ser. No. 09/232,257, Jan. 19, 1999 (now U.S. Pat. No. 6,141,102); Ser. No. 09/225,371, Jan. 4, 1999 (now U.S. Pat. No. 6,100,981); Ser. No. 09/225,076, Jan. 4, 1999 (now U.S. Pat. No. 5,963,325), which applications depend from application Ser. No. 08/997,311 filed Dec. 23, 1997, (now U.S. Pat. No. 5,946,098).

This application also Claims benefit of Provisional Application Ser. No. 60/527,554, Filed Dec. 6, 2003; and 60/527,638 Filed Dec. 8, 2003.

TECHNICAL FIELD

The present invention relates to ellipsometer systems, and more particularly to ellipsometer systems comprising transmissive rotating or stepwise rotatable compensators for continuously or step-wise varying polarization states and further comprising transmissive multi-element lens focusing of a spectroscopic electromagnetic beam into a small, chromatically relatively undispersed area spot on a material system. The ellipsometer system optionally is present in an environmental control chamber.

BACKGROUND

The practice of ellipsometry is well established as a non-destructive approach to determining characteristics of sample systems, and can be practiced in real time. The topic is well described in a number of publications, one such publication being a review paper by Collins, titled “Automatic Rotating Element Ellipsometers: Calibration, Operation and Real-Time Applications”, Rev. Sci. Instrum., 61(8) (1990).

In general, modern practice of ellipsometry typically involves causing a spectroscopic beam of electromagnetic radiation, in a known state of polarization, to interact with a sample system at least one angle of incidence with respect to a normal to a surface thereof, in a plane of incidence. (Note, a plane of incidence contains both a normal to a surface of an investigated sample system and the locus of said beam of electromagnetic radiation). Changes in the polarization state of said beam of electromagnetic radiation which occur as a result of said interaction with said sample system are indicative of the structure and composition of said sample system. The practice of ellipsometry further involves proposing a mathematical model of the ellipsometer system and the sample system investigated by use thereof, and experimental data is then obtained by application of the ellipsometer system. This is typically followed by application of a square error reducing mathematical regression to the end that parameters in the mathematical model which characterize the sample system are evaluated, such that the obtained experimental data, and values calculated by use of the mathematical model, are essentially the same.

A typical goal in ellipsometry is to obtain, for each wavelength in, and angle of incidence of said beam of electromagnetic radiation caused to interact with a sample system, sample system characterizing PSI and DELTA values, (where PSI is related to a change in a ratio of magnitudes of orthogonal components r_p/r_s in said beam of electromagnetic radiation, and wherein DELTA is related to a phase shift entered between said orthogonal components r_p and r_s, caused by interaction with said sample system. The basic equation relating PSI and DELTA is:

\[ \rho = \sqrt{r_p/r_s} = \tan(\Psi) \exp(i\Delta) \]

As alluded to, the practice of ellipsometry requires that a mathematical model be derived and provided for a sample system and for the ellipsometer system being applied. In that light it must be appreciated that an ellipsometer system which is applied to investigate a sample system is, generally, sequentially comprised of:

a. a Source of a beam electromagnetic radiation;
   b. a Polarizer element;
   c. optionally a compensator element;
   d. (additional element(s));
   e. a sample system;
   f. (additional element(s));
   g. optionally a compensator element;
   h. an Analyzer element; and
   i. a Spectroscopic Detector System.

Each of said components b.-i. must be accurately represented by a mathematical model of the ellipsometer system along with a vector which represents a beam of electromagnetic radiation provided from said source of a beam electromagnetic radiation, identified in a. above)

Various conventional ellipsometer configurations provide that a Polarizer, Analyzer and/or Compensator(s) can be rotated during data acquisition, and are describe variously as Rotating Polarizer (RPE), Rotating Analyzer (RAE) and Rotating Compensator (REC) Ellipsometer Systems. As described elsewhere in this Specification, the present invention provides that no element must be continuously rotated during data acquisition but rather that a sequence of discrete polarization states can be imposed during data acquisition. This approach allows eliminating many costly components from conventional rotating element ellipsometer systems, and, hence, production of an "Ultra-Low-Complexity" ellipsometer system. It is noted, that nulling ellipsometers also exist in which elements therein are rotatable in use, rather than rotating. Generally, use of a nulling ellipsometer system involves imposing a linear polarization state on a beam of electromagnetic radiation with a polarizer, causing the
resulting polarized beam of electromagnetic radiation to interact with a sample system, and then adjusting an analyzer to an azimuthal angle which effectively cancels out the beam of electromagnetic radiation which proceeds past the sample system. The azimuthal angle of the analyzer at which nulling occurs provides insight to properties of the sample system.

It is further noted that reflectometer systems are generally sequentially comprised of:

a. a Source of a beam electromagnetic radiation;

b. (optional additional element(s));

c. a sample system;

d. (optional additional element(s));

e. a Spectroscopic Detector System;

and that reflectometer systems monitor changes in intensity of a beam of electromagnetic radiation caused to interact with a sample system. That is, the ratio of, and phase angle between, orthogonal components in a polarized beam are not of direct concern.

Continuing, in use, data sets can be obtained with an ellipsometer system configured with a sample system present, sequentially for cases where other sample systems are present, and where an ellipsometer system is configured in a straight-through configuration wherein a beam of electromagnetic radiation is caused to pass straight through the ellipsometer system without interacting with a sample system. Simultaneous mathematical regression utilizing multiple data sets can allow evaluation of sample system characterizing PS и DELTA values over a range of wavelengths. The obtaining of numerous data sets with an ellipsometer system configured with, for instance, a sequence of sample systems present and/or wherein a sequential plurality of polarization states are imposed on an electromagnetic beam caused to interact therewith, can allow system calibration of numerous ellipsometer system variables.

Patents of which the Inventor are aware include those to Woollam et al, U.S. Pat. No. 5,373,359, Patent to Johns et al, U.S. Pat. No. 5,666,201 and Patent to Green et al., U.S. Pat. No. 5,521,706, and Patent to Johns et al., U.S. Pat. No. 5,504,582 are disclosed for general information as they pertain to ellipsometer systems.

Further Patents of which the Inventor are aware include U.S. Pat. Nos. 5,757,454 and 5,956,145 to Green et al., in which are taught a method for extending the range of bi-refringent component which is added, and the application thereof during data acquisition to enable the identified capability.

A Patent to Coates et al., U.S. Pat. No. 4,826,321 is disclosed as it describes applying a reflected monochromatic beam of plane polarized electromagnetic radiation at a Brewster angle of incidence to a sample substrate to determine the thickness of a thin film thereupon. This Patent also describes calibration utilizing two sample substrates, which have different depths of surface coating.

Other Patents which describe use of reflected electromagnetic radiation to investigate sample systems are U.S. Pat. Nos. RE 34,783, 4,373,817, and 5,045,704 to Coates; and U.S. Pat. No. 5,475,525 to Turner et al.

A Patent to Biork et al., U.S. Pat. No. 4,647,207 is disclosed as it describes an ellipsometer system which has provision for sequentially positioning a plurality of reflective polarization state modifiers in a beam of electromagnetic radiation. While said 207 Patent mentions investigating a sample system in a transmission mode, no mention or suggestion is found for utilizing a plurality of transmitting polarization state modifiers, emphasis added. U.S. Pat. Nos. 4,210,401; 4,332,476 and 4,355,903 are also identified as being cited in the 207 Patent. It is noted that systems as disclosed in these Patents, (particularly in the 476 Patent), which utilize reflection from an element to modify a polarization state can, that if such an element is an essential duplicate of an investigated sample and is rotated ninety degrees thereafter, then the effect of the polarization state modifying element on the electromagnetic beam effect is extinguished by the sample.

A Patent to Mansuripur et al., U.S. Pat. No. 4,838,695 is disclosed as it describes an apparatus for measuring reflectivity.

Patents to Rosencwaig et al., U.S. Pat. Nos. 4,750,822 and 5,595,406 are also identified as they describe systems which impinge electromagnetic beams onto sample systems at oblique angles of incidence. The 406 Patent provides for use of multiple wavelengths and multiple angles of incidence. For similar reasons U.S. Pat. No. 5,042,951 to Gold et al. is also disclosed.

A Patent to Osterberg, U.S. Pat. No. 2,700,918 describes a microscope with variable means for increasing the visibility of optical images, partially comprised of discrete bi-refringent plates which can be positioned in the pathway between an eyepiece and an observed object. Other Patents...
A U.S. Pat. No. 5,329,357 to Bernoux et al. is also identified as it claims use of fiber optics to carry electromagnetic radiation to and from an ellipsometer system which has at least one polarizer or analyzer that rotates during data acquisition. It is noted that if both the polarizer and analyzer are stationary during data acquisition that this Patent is not controlling where electromagnetic radiation carrying fiber optics are present.

A Patent to Chen et al., U.S. Pat. No. 5,581,350, is disclosed as it describes a method for regression calibration of ellipsometers.

As present invention preferred practice is to utilize a spectroscopic source of electromagnetic radiation with a relatively flat spectrum over a large range of wavelengths U.S. Pat. No. 6,628,917 to Koho; U.S. Pat. No. 5,179,462 to Kageyama et al. that the 594 Patent lens is not applied to directly focus relatively flat spectrum over a large range of wavelengths from the present invention lens structure and application to radiation, comprising an additional wavelength content, electromagnetic beam after its passage through the focusing that contains wavelengths from each of four sources of electromagnetic radiation. Each electromagnetic beam combining dichroic mirror in an arrangement which produces an output beam of electromagnetic radiation that contains wavelengths from each of four sources of electromagnetic radiation. A first wavelength content, therethrough so that it exits a second side of said electromagnetic beam combining dichroic mirror, and to reflect a second beam of electromagnetic radiation, comprising an additional wavelength content, from said second side of said electromagnetic beam combining dichroic mirror in a manner that a single output beam of electromagnetic radiation is formed which contains the wavelength content of both sources of electromagnetic radiation. The sources of electromagnetic radiation are described as lasers in said 462 Patent. Another U.S. Pat. No. 5,296,958 to Roddy et al., describes a similar system which utilizes Thompson Prisms to similarly combine electromagnetic beams for laser source. U.S. Pat. Nos. 4,982,206 and 5,113,279 to Kessler et al. and Hamamoto et al. respectively, describe similar electromagnetic electromagnetic beam combination systems in laser printer and laser beam scanning systems respectively. Another U.S. Pat. No. 3,947,688 to Massey, describes a method of generating tunable coherent ultraviolet light, comprising use of an electromagnetic electromagnetic beam combining system. A Patent to Miller et al., U.S. Pat. No. 5,155,625, describes a system for combining information beams in which a mirror comprising alternating regions of transparent and reflecting regions is utilized to combine transmitted and reflected beams of electromagnetic radiation into a single output beam. A Patent to Wright, U.S. Pat. No. 5,002,371 is also mentioned as describing a beam splitter system which operates to separate “P” and “S” orthogonal components in a beam of polarized electromagnetic radiation.

The most relevant Patent found is U.S. Pat. No. 5,917,594 to Norton. However, the system disclosed therein utilizes a spherical mirror to focus an electromagnetic beam onto the surface of a sample in the form of a small spot. Said system further develops both reflection and transmission signals via application of reflective means and of reflection and transmission detectors. The somewhat relevant aspect of the 594 Patent system is that a positive lens and a negative meniscus lens are combined and placed into the path of the electromagnetic beam prior to its reflection from a focusing spherical mirror. The purpose of doing so is to make the optical system, as a whole, essentially achromatic in the visible wavelength range, and even into the ultraviolet wavelength range. It is further stated that the power of the combined positive lens and negative meniscus lens is preferably zero. It is noted that, as described elsewhere in this Specification, said 594 Patent lens structure, positioning in the 594 Patent system, and purpose thereof are quite distinct from the present invention lens structure and application to a focus a beam of electromagnetic radiation. In particular, note that the 594 Patent lens is not applied to directly focus and/or recollimate a beam of electromagnetic radiation onto a sample system, as do the lenses in the present invention. And, while the present invention could utilize a meniscus lens in an embodiment thereof, the 594 Patent specifically requires and employs a negative meniscus lens to correct for spherical aberrations caused by off-axis reflection from a spherical mirror, in combination with a positive lens to correct for achromatic aberration introduced by said negative meniscus lens. Further, the present invention system does not require reflection means be present in the path of an electromagnetic beam after its passage through the focusing lens thereof and prior to interacting with a sample system, as does the system in the 594 Patent wherein a focusing spherical mirror is functionally required.


Another paper, by Gottesfeld et al., titled “Combined Ellipsometer and Reflectometer Measurements of Surface Processes on Nobel Metals Electrodes”, Surface Sci., 56 (1976), is also identified as describing the benefits of combining ellipsometry and reflectometry.

A paper by Smith, titled “An Automated Scanning Ellipsometer”, Surface Science, Vol. 56, No. 1. (1976), is also mentioned as it describes an ellipsometer system which does not require any moving, (e.g., rotating), elements during data acquisition.


A paper by Jones titled “A New Calculus For The Treatment Of Optical Systems”, J.O.S.A., Vol. 31, (July 1941), is also identified as it describes the characterizing of multiple lens elements which separately demonstrate birefringence, as a single lens, (which can demonstrate reduced birefringence).

Finally, a paper which is co-authored by inventors herein is titled “In Situ Multi-Wavelength Ellipsometric Control of Thickness and Composition of Bragg Reflector Structures”, by Herzinger, Johns, Reich, Carpenter & Van Hove, Mat. Res. Soc. Symp. Proc., Vol. 406, (1996) is also disclosed.

Even in view of relevant prior art, there remains need for a spectroscopic ellipsometer system which:

- Presents with stationary polarizer and analyzer during data acquisition;
- Utilizes a plurality of transmissive step-wise rotatable or rotating compensator means to effect a plurality of sequential polarization states during said data acquisition;
- Which includes at least one multi-element lens; and
- A source of spectroscopic electromagnetic radiation and/or a spectroscopic multi-element detector system therewith.

The present invention provides a system with the identified attributes.

DISCLOSURE OF THE INVENTION

The present invention is, in the first instance, a spectroscopic ellipsometer system basically comprising:

- A source of polychromatic electromagnetic radiation;
- A polarizer which is fixed in position during data acquisition;
- A stage for supporting a sample system;
- An analyzer which is fixed in position during data acquisition; and
- A multi-element spectroscopic detector system.

In addition, the present invention ellipsometer system further comprises at least one means for continuously or discreetly, sequentially, modifying a polarization state of a beam of electromagnetic radiation through a plurality of polarization states. The at least one means for continuously or discreetly, sequentially, modifying a polarization state of a beam of electromagnetic radiation through a plurality of polarization states, is positioned between said polarizer and said stage for supporting a sample system, and/or between said stage for supporting a sample system and said analyzer, so that said beam of electromagnetic radiation transmits through a polarization state modifier element thereof in use. The present invention at least one means for continuously or discreetly, sequentially, modifying a polarization state of a beam of electromagnetic radiation through a plurality of polarization states comprises a compensator which is mounted to allow rotation about the locus of a beam of electromagnetic radiation caused to pass therethrough.

Said spectroscopic ellipsometer system further comprises at least one multiple element lens present at least one location selected from the group consisting of:

- Between said polarizer and said stage for supporting a sample system; and
- Between said stage for supporting a sample system and said analyzer;

and positioned so that said beam of electromagnetic radiation transmits therethrough in use.

The present invention is further a combination spectroscopic reflectometer/ellipsometer system basically comprising:

- A source of polychromatic electromagnetic radiation;
- A stage for supporting a sample system;
- A multi-element spectroscopic detector system.

The combination spectroscopic reflectometer/ellipsometer system further comprises, in the ellipsometer system portion thereof, a polarization, (which is fixed in position during data acquisition), present between the source of polychromatic electromagnetic radiation and the stage for supporting a sample system, and an analyzer, (which is fixed in position during data acquisition), present between the stage for supporting a sample system and the multi-element spectroscopic detector system. The ellipsometer system also comprises at least one means for discreetly, sequentially, modifying a polarization state of a beam of electromagnetic radiation through a plurality of polarization states present between said polarizer and said stage for supporting a sample system, and/or between said stage for supporting a sample system and said analyzer, and positioned so that said beam of electromagnetic radiation transmits through a polarization state modifier element therein during use.

Additionally, the combination spectroscopic reflectometer/ellipsometer system is configured such that a polychromatic beam of electromagnetic radiation provided by said source of polychromatic electromagnetic radiation can, optionally, be directed to interact with a sample system present on said stage for supporting a sample system without any polarization state being imposed thereupon, and such that a polychromatic beam of electromagnetic radiation also provided by said source of polychromatic electromagnetic radiation can be, optionally simultaneously, directed to interact with a sample system present on said stage for supporting a sample system after a polarization state has been imposed thereupon. The polychromatic beam of electromagnetic radiation without any polarization state imposed thereupon, when directed to interact with a sample system present on said stage for supporting a sample system, is typically caused to approach said sample system at an oblique angle of incidence which is between a sample system Brewster angle and a normal to the surface of the sample system. Further, the polychromatic beam of electromagnetic radiation provided by said source of polychromatic electromagnetic radiation upon which a polarization state has been imposed, is typically directed to interact with a sample system present on said stage for supporting a sample system at an angle near the Brewster angle of the sample system being investigated. Either, or both, the polychromatic beam(s) of electromagnetic radiation provided by said source of polychromatic electromagnetic radiation, upon which is imposed a polarization state or upon which no polarization state is imposed, is preferably directed to interact with a sample system present on said stage for supporting a sample system via a fiber optic means.
While the present invention can utilize essentially any compensator such as:

- Berek-type with optical axis essentially perpendicular to a surface thereof;
- non-Berek-type with an optical axis essentially parallel to a surface thereof;
- zero-order wave plate; zero-order waveplate constructed from two multiple order waveplates;
- a sequential plurality of zero-order waveplates, each constructed from a plurality of multiple order waveplates;
- a multiple element compensator; which first triangular shaped element and second triangular shaped element along an essentially horizontally oriented locus, is caused to externally reflect from an outer surface thereof and travel along a locus which is essentially upwardly oriented, then enter said second triangular shaped element and essentially totally internally reflect from one of said first and second sides thereof, then proceed along an essentially downward vertically oriented locus, then externally reflect from the other of said first and second sides and proceed along an essentially horizontally oriented locus which is undeviated and undisplaced from the essentially horizontally oriented locus of said input beam of essentially horizontally oriented electromagnetic radiation even when said retarder is caused to rotate; with a result being that retardation is entered between orthogonal components of said input electromagnetic beam of radiation;

a compensator system comprised of at least one zero-order waveplate, ((MOA) or (MOB)), and at least one effective zero-order waveplate, ((ZOl) or (ZOl)) respectively, said effective zero-order wave plate, ((ZOl2) or (ZOl1)), being comprised of two multiple order waveplates which are combined with the fast axes thereof oriented at a nominal ninety degrees to one another, the fast axes of the multiple order waveplates in said effective zero-order wave plate, ((ZOl2) or (ZOl1)), being rotated to a position away from zero or ninety degrees with respect to the fast axis of the zero-order waveplate, ((MOA) or (MOB));

where the identifiers are shown in FIGS. 3e–3i.

Additional compensator systems, previously disclosed in patent application Ser. No. 08/997,311, (now U.S. Pat. No. 5,946,098), and CIP’s therefrom, which are specifically within the scope of the invention and can be included in the selection group are:

a compensator system comprised of a first triangular shaped element, which as viewed in side elevation presents with first and second sides which project to the left and right and downward from an upper point, which first triangular shaped element first and second sides have reflective outer surfaces; said retarder system further comprising a second triangular shaped element which as viewed in side elevation presents with first and second sides which project to the left and right and downward from an upper point, said second triangular shaped element being made of material which provides reflective interfaces on first and second sides inside thereof; said second triangular shaped element being oriented with respect to the first triangular shaped element such that the upper point of said second triangular shaped element is oriented essentially vertically directly above the upper point of said first triangular shaped element; such that in use an input electromagnetic beam of radiation caused to approach one of said first and second sides of said first triangular shaped element along an essentially horizontally oriented locus, is caused to externally reflect from an outer surface thereof and travel along a locus which is essentially upwardly oriented, then enter said second triangular shaped element and essentially totally internally reflect from one of said first and second sides thereof, then proceed along an essentially horizontal locus and essentially totally internally reflect from the other of said first and second sides and proceed along an essentially downward vertically oriented locus, then externally reflect from the other of said first and second sides of said first triangular shaped elements and proceed along an essentially horizontally oriented locus which is undeviated and undisplaced from the essentially horizontally oriented locus of said input beam of essentially horizontally oriented electromagnetic radiation even when said retarder is caused to rotate; with a result being that retardation is entered between orthogonal components of said input electromagnetic beam of radiation;
a compensator system comprised of first and second orientation adjustable mirrored elements such that in use an input electromagnetic beam of radiation caused to approach one of said first and second orientation adjustable mirrored elements along an essentially horizontally oriented locus, is caused to externally reflect therefrom and travel along a locus which is essentially upwardly vertically oriented, then enter said third element and essentially totally internally reflect from one of said first and second sides thereof, then proceed along an essentially horizontal locus and essentially totally internally reflect from the other of said first and second sides and proceed along an essentially downward vertically oriented locus, then reflect from the other of said first and second orientation adjustable mirrored elements and proceed along an essentially horizontally oriented propagation direction locus which is essentially undeviated and undisplaced from the essentially horizontally oriented propagation direction locus of said input beam of essentially horizontally oriented electromagnetic radiation even when said compensator/retarder is caused to rotate; with a result being that retardation is entered between orthogonal components of said input electromagnetic beam of radiation;

a compensator system comprised of a parallelogram shaped element which, as viewed in side elevation, has top and bottom sides parallel to one another, both said top and bottom sides being oriented essentially horizontally, said retarder system also having right and left sides parallel to one another, both said right and left sides being oriented at an angle to horizontal, said retarder being made of a material with an index of refraction greater than that of a surrounding ambient; such that in use an input beam of electromagnetic radiation caused to enter a side of a triangular shaped element selected from the group consisting of: (right and left), along an essentially horizontally and which is continuous with, and second triangular shaped elements being positioned so that a rightmost side of one of said first and second triangular shaped elements is in contact with a leftmost side of the other of said first and second triangular shaped elements over a portion of the lengths thereof; said first and second triangular shaped elements each being made of material with an index of refraction greater than that of a surrounding ambient; such that in use an input beam of electromagnetic radiation caused to enter a side of a triangular shaped element selected from the group consisting of: (first and second), not in contact with said other triangular shape element, is caused to diffracted inside said retarder and follow a locus which causes it to essentially totally internally reflect from internal interfaces of said third sides of each of said first and second triangular shaped elements, and emerge from a side of said triangular shaped element selected from the group consisting of: (second and first); said retarder system being made of a material with an index of refraction greater than that of a surrounding ambient; such that in use an input beam of electromagnetic radiation caused to enter a side of a retarder system selected from the group consisting of: (first and second), along an essentially horizontally oriented locus, is caused to diffracted inside said retarder system and follow a locus which causes it to essentially totally internally reflect from internal interfaces of both said top and bottom sides, and emerge from said retarder system from a side selected from the group consisting of (left and right respectively), along an essentially horizontally oriented locus which is undeviated and undisplaced from the essentially horizontally oriented locus of said input beam of essentially horizontally oriented electromagnetic radiation even when said retarder is caused to rotate; with a result being that retardation is entered between orthogonal components of said input electromagnetic beam of radiation; and

a compensator system comprised of first and second Berek-type retarders which each have an optical axes essentially perpendicular to a surface thereof, each of which first and second Berek-type retarders has a fast axis, said fast axes in said first and second Berek-type retarders being oriented in an orientation selected from the group consisting of: (parallel to one another and other than parallel to one another); said first and second Berek-type retarders each presenting with first and second essentially parallel sides, and said first and second Berek-type retarders being oriented, as viewed in side elevation, with first and second essentially parallel sides, and said first and second Berek-type retarders being oriented other than parallel to first and second sides of the other Berek-type retarder;
such that in use an incident beam of electromagnetic radiation is caused to impinge upon one of said first and second Berek-type retarders on one side thereof; partially transmit therethrough then impinge upon the second Berek-type retarder on one side thereof; and partially transmit therethrough such that a polarized beam of electromagnetic radiation passing through both of said first and second Berek-type retarders emerges from the second thereof in a polarized state with a phase angle between orthogonal components therein which is different than that in the incident beam of electromagnetic radiation, and in a propagation direction which is essentially undeviated and undisplaced from the incident beam of electromagnetic radiation even when said retarder system is caused to rotate; with a result being that retardation is entered between orthogonal components of said input electromagnetic beam of radiation;

a compensator system comprised of first and second Berek-type retarders which each have an optical axes essentially perpendicular to a surface thereof, each of which first and second Berek-type retarders has a fast axis, said fast axes in said first and second Berek-type retarders being oriented other than parallel to one another, said first and second Berek-type retarders each presenting with first and second essentially parallel sides, and said first and second Berek-type retarders being oriented, as viewed in side elevation, with first and second sides of one Berek-type retarder being oriented other than parallel to the fast axes of said first and second Berek-type retarders, said first Berek-type retarder being oriented essentially parallel to one another but other than parallel to the fast axes of said first and second Berek-type retarders, said first and second Berek-type retarders each presenting with first and second essentially parallel sides, and said first and second Berek-type retarders being oriented, as viewed in side elevation, with first and second sides of one of said third and forth Berek-type retarders being oriented other than parallel to first and second sides of said forth Berek-type retarder; such that in use an incident beam of electromagnetic radiation is caused to impinge upon one of said first and second Berek-type retarders on one side thereof, partially transmit therethrough then impinge upon the second Berek-type retarder on one side thereof, and partially transmit therethrough such that a polarized beam of electromagnetic radiation passing through both of said first and second Berek-type retarders emerges from the second thereof in a polarized state with a phase angle between orthogonal components therein which is different than that in the incident beam of electromagnetic radiation, and in a propagation direction which is essentially undeviated and undisplaced from the incident beam of electromagnetic radiation, said compensator system further comprising third and forth Berek-type retarders which each have an optical axes essentially perpendicular to a surface thereof, each of which third and forth Berek-type retarders has a fast axis, said fast axes in said third and forth Berek-type retarders being oriented other than parallel to one another, said third and forth Berek-type retarders each presenting with first and second essentially parallel sides, and said third and forth Berek-type retarders being oriented, as viewed in side elevation, with first and second sides of one of said third and forth Berek-type retarders being oriented other than parallel to first and second sides of said forth Berek-type retarder; such that in use an incident beam of electromagnetic radiation exiting said second Berek-type retarder is caused to impinge upon said third Berek-type retarder on one side thereof, partially transmit therethrough then impinge upon said forth Berek-type retarder on one side thereof, and partially transmit therethrough such that a polarized beam of electromagnetic radiation passing through said first, second, third and forth Berek-type retarders emerges from the forth thereof in a polarized state with a phase angle between orthogonal components therein which is different than that in the incident beam of electromagnetic radiation caused to impinge upon the first side of said first Berek-type retarder, and in a direction which is essentially undeviated and undisplaced from said incident beam of electromagnetic radiation even when said retarder system is caused to rotate; with a result being that retardation is entered between orthogonal components of said input electromagnetic beam of radiation;
said compensator causing essentially no deviation or displacement in a polychromatic beam of electromagnetic radiation caused to pass therethrough while caused to rotate.

It is to be appreciated that the present Application can apply Compensator(s) in a system which causes continuous rotation thereof during data acquisition, or steps a compensator through a series of discrete rotational positions, and holds it stationary while obtaining data. Further, while not required, the present invention benefits from Compensator(s) designed to provide relatively constant, achromatic Polarization State Modification effects over a Spectroscopic range of wavelengths.

Continuing, said at least one multiple element lens present at least one location selected from the group consisting of:

a) at least one thereof comprises:
   two sequentially oriented elements, one of said two sequentially oriented elements being of a shape and orientation which individually diverges a beam of electromagnetic radiation caused to pass therethrough, and the other being of a shape and orientation which individually converges a beam of electromagnetic radiation caused to pass therethrough, there being a region between said at least two elements such that, in use, a beam of electromagnetic radiation sequentially passes through one of said at least two elements, then said region therebetween, and then the other of said at least two elements before emerging as an effectively converged, focused, beam of electromagnetic radiation.

b) at least one thereof comprises:
   a sequential combination of a bi-convex element and a bi-concave element.

c) at least one thereof comprises:
   a sequential combination of a bi-concave element and a bi-convex element.

d) at least one thereof comprises:
   a sequential combination of a bi-convex element and a plano-concave element with said concave side of said plano-concave element adjacent to said bi-convex element.

e) at least one thereof comprises:
   a sequential combination of a bi-concave element and a plano-convex element with said essentially flat side of said plano-convex element adjacent to said bi-concave element.

f) at least one thereof comprises:
   a sequential combination of a plano-concave element and a bi-convex element with said essentially flat side of said plano-concave element adjacent to said bi-convex element.

g) at least one thereof comprises:
   a sequential combination of a plano-concave element and bi-convex element with said concave side of said plano-concave element adjacent to said bi-convex element.

h) at least one thereof comprises:
   a sequential combination of a plano-convex element and a bi-concave element with said essentially flat side of said plano-convex element adjacent to said bi-concave element.

i) at least one thereof comprises:
   a sequential combination of a bi-concave element with a plano-convex element with said convex side of said plano-convex element adjacent to said bi-concave element.

j) at least one thereof comprises:
   a sequential combination of a plano-concave element and a plano-convex element with the essentially flat side of said plano-concave element being adjacent to the convex side of the plano-convex element.

k) at least one thereof comprises:
   a sequential combination of a plano-concave element and a plano-convex element with the essentially flat side of said plano-concave element being adjacent to the flat side of said plano-convex element.

l) at least one thereof comprises:
   a sequential combination of a plano-convex element and a plano-concave element with the essentially flat side of said plano-convex element and the essentially flat side of said plano-concave element being adjacent to one another.

m) at least one thereof comprises:
   a sequential combination of a plano-concave element and a plano-convex element with the concave side of said plano-concave element being adjacent to the convex side of the plano-convex element.

n) at least one thereof comprises:
   a sequential combination of a plano-convex element bi-concave element with said convex side of said plano-convex element adjacent to said bi-concave element.

o) at least one thereof comprises:
   a sequential combination of a bi-concave element and a plano-convex element with said essentially flat side of said plano-convex element adjacent to said bi-concave element.

p) at least one thereof comprises:
   a sequential combination of a plano-convex element and a plano-concave element with said convex side of said plano-concave element adjacent to the concave side of the plano-convex element.

q) at least one thereof comprises:
   a sequential combination of a plano-concave element and a plano-convex element with said essentially flat side of said plano-concave element being adjacent to the essentially convex side of the plano-convex element.

r) at least one thereof comprises:
   a sequential combination of a plano-convex element and a plano-concave element with said convex side of said plano-concave element being adjacent to the essentially flat side of the plano-convex element.

s) at least one thereof comprises:
   a sequential combination of a plano-concave element and a plano-convex element with the essentially flat side of said plano-concave element being adjacent to the concave side of said plano-concave element.
and wherein each of said at least two elements are individually selected to be made of different materials;

w) at least one thereof is characterized by at least one selection from the group consisting of:
   a) the focal length is between forty and forty-one millimeters over a range of wavelengths of at least two-hundred to seven-hundred nanometers;
   b) the focal length varies by less than five (5%) percent over a range of wavelengths of between two-hundred and five-hundred nanometers; and
   c) the spot diameter at the focal length is less than seventy-five microns over a range of wavelengths of at least two-hundred to seven-hundred nanometers;

x) at least one thereof comprises:
   an element made of a selection from the group consisting of:
      CaF$_2$; and
      fused silica;

y) at least one thereof:
   is made of two elements, one of said elements being made of Fused Silica and the other of CaF$_2$;

z) at least one thereof comprises:
   a converging element selected from the group consisting of:
      a) a source of a spectroscopic beam electromagnetic radiation;
      b) a analyzer element;
in either order elements c and d;
c) optionally a compensator element;
d) said input lens;
e) a material system;
in either order elements f and g;
f) said output lens;
g) optionally a compensator element;
h) an analyzer element; and
i) a detector System.

As demonstrated in Patent Nos. 5,929,995 and 5,969,818 beam directing means and/or windows can be located at least one selection from the group consisting of:
a) between said source of a spectroscopic beam electromagnetic radiation and said material system; and
b) between said material system and said detector system.
The disclosed invention can also be described as a system for monitoring change in:
the intensity of; and/or
the ratio of and/or
the phase between orthogonal components in;
a spectroscopic beam of electromagnetic radiation which is caused by interaction with a material system;
said system comprising at least one lens which is of multiple element construction and positioned so that beam of electromagnetic radiation transmits therethrough, wherein, at least two elements thereof are made from different materials, such that in use the focal length for each wavelength in a range of wavelengths is within an acceptable range of focal lengths;
said at least one multiple element lens being characterized by at least one selection from the group consisting of:
a) the focal length is between forty and forty-one millimeters over a range of wavelengths of at least two-hundred to seven-hundred nanometers;
b) the focal length varies by less than five (5%) percent over a range of wavelengths of between two-hundred and five-hundred nanometers; and
c) the spot diameter at the focal length is less than seventy-five microns over a range of wavelengths of at least two-hundred to seven-hundred nanometers;
said system further comprising at least one compensator positioned so that beam of electromagnetic radiation transmits therethrough, said compensator being characterized by a selection from the group consisting of:
said at least one compensator(s) produces a retardance of between seventy-five (75) and one-hundred-thirty (130) degrees over a range of wavelengths defined by a selection from the group consisting of:
a) between one-hundred-ninety (190) and seven-hundred-fifty (750) nanometers;
b) between two-hundred-forty-five (245) and nine-hundred (900) nanometers;
c) between three-hundred-eighty (380) and seventeen-hundred (1700) nanometers;
d) within a range of wavelengths defined by a maximum wavelength (MAXW) and a minimum wavelength (MINW) wherein the ratio of (MAXW) to (MINW) is at least one-and-eight-tenths (1.8); and
said at least one compensator(s) produces a retardation between thirty (30.0) and less than one-hundred-thirty-five (355) degrees over a range of wavelengths specified from MINW to MAXW by a selection from the group consisting of:
a. MINW less than/equal to one-hundred-ninety (190) and MAXW greater than/equal to seventeen-hundred (1700);
b. MINW less than/equal to two-hundred-twenty (220) and MAXW greater than/equal to one-thousand (1000) nanometers;
c. within a range of wavelengths defined by a maximum wavelength (MAXW) and a minimum wavelength (MINW) range where (MAXW)/(MINW) is at least four-and-one-half (4.5).

Said at least one multiple element lens comprises at least two elements which are made from different materials independently selected from the group consisting of:
CaF₂;
BaF₂;
LiF;
MgF₂;
fused silica;
a void region;
a gas filled region;
a liquid filled region; and a functional equivalent to a void region.
During data collection, said at least one compensator can be caused to perform motion selected from the group consisting of:
continuously rotates; and
sequentially rotates through a plurality of discrete angles;
around an axis defined by the locus of the spectroscopic electromagnetic beam as it transmits therethrough.

Regarding the at least one multiple element lens, it typically demonstrates at least some birefringence.
As another previously disclosed, (in Co-Pending application Ser. No. 09/517,125), non-limiting example, the spectroscopic ellipsometer system can provide at least one means for discretely, sequentially, modifying a polarization state of a beam of electromagnetic radiation provided by said source of polychromatic electromagnetic radiation through a plurality of polarization states, can comprise an essentially circular "wheel" element with a plurality of discrete polarization state modifier elements mounted thereupon, on the perimeter thereof, and projecting perpendicularly to a surface of said essentially circular "wheel". The essentially circular "wheel" element further comprises a means for causing rotation about a normal to said surface thereof, such that in use said essentially circular "wheel" element is caused to rotate to position a discrete polarization state modifier element such that the beam of electromagnetic radiation, provided by said source of polychromatic electromagnetic radiation, passes therethrough.

As another previously disclosed, (in Co-Pending application Ser. No. 09/517,125), non-limiting example, the spectroscopic ellipsometer system at least one means for discretely, sequentially, modifying a polarization state of a beam of electromagnetic radiation provided by said source of polychromatic electromagnetic radiation through a plurality of polarization states, can comprise a plurality of discrete polarization state modifier elements mounted on a slider element which is mounted in a guide providing element. During use sliding the slider element to the right or left serves to position a discrete polarizer element such that said beam of electromagnetic radiation, provided by said source of polychromatic electromagnetic radiation, passes therethrough.
Continuing, again as previously disclosed, (in application Ser. No. 09/517,125, now U.S. Pat. No. 6,268,917), it is further noted that a system for providing an output beam of
magnetic radiation, which has a relatively broad and flattened intensity vs. wavelength characteristic over a wavelength spectrum for use in said present invention systems can be applied in the present invention system. The reason for doing so is to provide an output beam of polychromatic electromagnetic radiation which is substantially a comingled composite of a plurality of input beams of polychromatic electromagnetic radiation which individually do not provide as relatively broad and flattened intensity vs. wavelength characteristic over said wavelength spectrum, as does said output comingled composite beam of polychromatic electromagnetic radiation. The system for providing an output beam of polychromatic electromagnetic radiation, which has a relatively broad and flattened intensity vs. wavelength characteristic over a wavelength spectrum, comprises:

a. at least a first and a second source of polychromatic electromagnetic radiation; and

b. at least a first electromagnetic beam combining means comprising a plate, (e.g., uncoated fused silica or glass etc. such that transmission characteristics thereof are determined by angle-of-incidence and polarization state of a beam of electromagnetic radiation).

The at least a first electromagnetic beam combining means is positioned with respect to said first and second sources of polychromatic electromagnetic radiation such that a beam of polychromatic electromagnetic radiation from said first source of polychromatic electromagnetic radiation passes through said at least a first electromagnetic beam combining means, and such that a beam of polychromatic electromagnetic radiation from said second source of polychromatic electromagnetic radiation reflects from said at least a first electromagnetic beam combining means and is comingled with said beam of polychromatic electromagnetic radiation which passes through said at least a first electromagnetic beam combining means. The resultant beam of polychromatic electromagnetic radiation exiting the first electromagnetic beam combining means is substantially an output beam of polychromatic electromagnetic radiation which has a relatively broad and flattened intensity vs. wavelength over a wavelength spectrum, comprising said comingled composite of a plurality of input beams of polychromatic electromagnetic radiation which individually do not provide such a relatively broad and flattened intensity vs. wavelength over a wavelength spectrum characteristic.

Said system for providing an output beam of polychromatic electromagnetic radiation which has a relatively broad and flattened intensity vs. wavelength characteristic over a wavelength spectrum can also be optionally further characterized by a third source of polychromatic electromagnetic radiation, and/or a second electromagnetic beam combining (BCM) means comprising an uncoated plate, (e.g. fused silica or glass etc. such that transmission characteristics thereof are determined by angle-of-incidence and polarization state of a beam of electromagnetic radiation). The second electromagnetic beam combining means, when present, is positioned with respect to said comingled beam of polychromatic electromagnetic radiation which has a relatively broad and flattened intensity vs. wavelength over a wavelength spectrum which exit said at least a first electromagnetic beam combining means, such that it passes through said second electromagnetic beam combining means. The second electromagnetic beam combining means is also positioned with respect to the third source of polychromatic electromagnetic radiation, (when present), such that a beam of electromagnetic radiation from said third source of polychromatic electromagnetic radiation reflects from said second electromagnetic beam combining means, such that a second resultant beam of polychromatic electromagnetic radiation which is substantially an output beam of polychromatic electromagnetic radiation which has a relatively even more broadened and flattened intensity vs. wavelength over a wavelength spectrum, comprising said comingled composite of a plurality of input beams of polychromatic electromagnetic radiation from said first, second and third sources, which first, second and third sources individually do not provide such a relatively even more broadened and flattened intensity vs. wavelength over a wavelength spectrum characteristic.

At least one of said first and second, (when present), electromagnetic beam combining means can be pivotally mounted such that, for instance, the angle at which a beam of polychromatic electromagnetic radiation from the second source of polychromatic electromagnetic radiation reflects from the at least one electromagnetic beam combining means can be controlled to place it coincident with the locus of a beam of polychromatic electromagnetic radiation transmitted therethrough. Pivot means providing two dimensional degrees of rotation freedom are preferred in this application. Further, where sources of polychromatic electromagnetic radiation can be moved, the pivot capability can be utilized to allow use of optimum tilts of electromagnetic beam combining means. That is, transmission and reflection characteristics of an electromagnetic beam combining means vary with the angle of incidence a transmitted or reflected beam makes with respect thereto, and pivot means can allow adjusting tilt to optimize said characteristics.

Further, as the polarizer in the present invention spectroscopic ellipsometer system remains essentially fixed in position during data acquisition, it is noted that it is preferable that a source of electromagnetic radiation, and/or a present Polarizer or Polarization State Generator be positioned or configured so as to pass predominantly “S” Polarized electromagnetic radiation, as referenced to said beam combining system. The reason for this is that the split between “S” polarization transmission and reflection components is less, as a function of wavelength and electromagnetic beam angle-of-incidence to said beam combining means, when compared to that of the “P” components. The “P” component is far more affected, particularly around a Brewster angle condition, hence, where an “S” component, with reference to a beam combining system, is utilized, it is to be appreciated that variation in intensity of transmitted and reflected beams of electromagnetic radiation output from the beam combining system, as functions of wavelength and the angles of incidence of beams of electromagnetic radiation from sources of said transmitted and reflected beams of electromagnetic radiation, is minimized, as compared to variation which occurs in “P” components.

It is noted that the polarizer and analyzer thereof, which are essentially fixed in position during data acquisition, are not necessarily absolutely fixed in position. Said polarizer and analyzer are preferably what is properly termed “Rotatable”. That is they can be rotated to various positions by user between data acquisitions, but they are not caused to be Rotating while data is being acquired. (Typical positioning of analyzer and polarizer azimuthal angles are plus or minus forty-five (+/-45) degrees).

It is also noted that operation of the present invention can be generally improved by improving the quality of the electromagnetic radiation.
A first approach is to provide a back reflector behind a source of electromagnetic radiation, which serves to direct electromagnetic radiation which exits the source in a useful direction.

Another approach is to provide a reflecting means in the pathway of the electromagnetic beam, upon which reflecting means is a coating which emphasises reflection of the UV and particularly at 193 nm. An example of such a coating on a reflective means is 600 Angstroms of Silicon Dioxide atop Silicon. This approach enables setting "gain" providing means at higher levels to emphasize UV signals, while not over amplifying, and even saturating higher intensity wavelengths signals.

Another approach is to coat transmissive elements such as lenses present in the system, to minimize entry and exit losses caused thereby, and improve overall UV transmission therethrough. An example is a single 300 Angstrom layer of MgF2. Multilayer coatings can also be used.

Another approach is to provide a Grating which has characteristics that emphasize UV wavelengths and/or direct a utilized “Order” of wavelengths in a direction which is subject to less influence by the zero and/or other orders.

Further, application of baffling to block access of zero and/or other orders of electromagnetic radiation to detector means can be applied.

Approaches which focus on optical fibers are:

Another approach is to eliminate optical fibers which, while convenient for use directing electromagnetic radiation, also serve to attenuate UV wavelength intensity via entry loss and transmission attenuation.

However, if optical fibers are utilized, to reduce UV intensity at fiber entry loss a narrow slit (eg. smaller that the fiber dimension), can be placed at the entry to the fiber.

The following approaches focus on increasing the amount of UV electromagnetic radiation and can be practiced independently or in combination:

Another approach is to utilize a source of electromagnetic radiation which emphasises UV wavelength production. Various wattage lamps (eg. 35, 75 and 150 can be applied and where necessary can involve application of various indirect heat sink based cooling and produced ozone containment.

Another approach is to, in the case of rotating compensator ellipsometers, reduce the rotation speed of the compensator so that for the same number of rotations more total electromagnetic radiation passes therethrough and reaches the detector.

Another approach is to take multiple scans of data to improve signal to noise.

Another approach is to combine the output of multiple pixels in a detector which receive UV radiation.

It is also disclosed that the presently disclosed spectroscopic ellipsometer can be mounted in a Chamber for controlling the ambient. Examples of the Chamber are:

it comprises at least one chamber region in which is present polarization state generator comprising component(s) prior to said material system; and polarization state detector comprising component(s) after said material system;

it comprises at least three chamber regions, in one of which is present polarization state generator comprising component(s) prior to said material system, in the second of which is present the material system and in the third of which is present polarization state detector comprising component(s) after said material system;

it comprises at least two chamber regions, in one of which is present polarization state generator comprising component(s) prior to said material system, and in the second of which is present polarization state detector comprising component(s) after said material system;

It is believed that the present invention spectroscopic ellipsometer system combination comprising:

polarizer and analyzer, (which are both fixed in position during data acquisition); and

at least one rotating or stepwise rotatable compensator means for discretely, sequentially, modifying a polarization state of a beam of electromagnetic radiation provided by said source of polychromatic electromagnetic radiation through a plurality of polarization states, said means being present at least one location selected from the group consisting of:

between said polarizer and said stage for supporting a sample system; and

between said stage for supporting a sample system and said analyzer; and

said at least one rotating or stepwise rotatable compensator means for discretely, sequentially, modifying a polarization state of a beam of electromagnetic radiation provided by said source of polychromatic electromagnetic radiation through a plurality of polarization states, and said at least one multiple element lens being positioned so that said beam of electromagnetic radiation transmits therethrough in use;

is Patentably distinct over all prior art other than Patents which are co-owned by the J.A. Woollam Co. Inc. from which this Application Continues-In-Part or from which this Application otherwise has priority benefit.

The present invention will be better understood by reference to the Detailed Description Section of this Specification, in combination with the Drawings.

SUMMARY

It is therefore a primary purpose and/or objective of the present invention to disclose a combination of:

spectroscopic ellipsometer and combined spectroscopic reflectometer/ellipsometer systems, which present invention system includes, in the spectroscopic ellipsometer portion thereof, provision of polarizer and analyzer elements which are fixed in position during data acquisition procedures, and at least one continuously rotating or stepwise rotatable compensator means for imposing a plurality of sequentially discrete, rather than continuously varying, polarization states onto a beam of electromagnetic radiation caused to be present in said spectroscopic ellipsometer system; and
multi-element lens systems which enables practice of focused beam small-spot spectroscopic ellipsometry over a large wavelength range, including into the deep UV, (eg. wavelengths down to and below 190 NM); (multielement lenses which comprise elements made of different materials allow essentially the same focal length to be achieved over a wide wavelength range being preferred).

It is yet another purpose and/or objective of the presently disclosed invention to disclose a preferred, but not limiting, source of electromagnetic radiation which provides a plurality of wavelengths combined from a plurality of sources. It is another purpose and/or objective yet of the presently disclosed invention to teach containing a spectroscopic ellipsometer in an environmental chamber.

Other purposes and/or objectives will become clear from a reading of the Specification and Claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a present invention spectroscopic ellipsometer system configuration.

FIG. 2 shows a combined present invention spectroscopic reflectometer/ellipsometer system.

FIG. 3a shows a frontal perspective view of a discrete state polarizer comprising a wheel with five discrete polarizer elements mounted thereupon.

FIG. 3b shows a side elevational view of a discrete state polarizer, as in FIG. 3a, oriented so that an electromagnetic beam passing through one of the discrete polarizer five elements.

FIG. 3c shows a front elevational view of a discrete state polarizer with five laterally slide mounted discrete polarizer elements mounted therein.

FIG. 3d shows a present invention system for providing an output beam (OB) or (OB)' of polychromatic electromagnetic radiation which has a relatively broad and flattened intensity vs. wavelength characteristic over a wavelength spectrum.

FIGS. 3e-3f demonstrate functional construction of preferred present invention compensator systems.

FIGS. 3i-3p show additional functional construction of compensator systems which are within the scope of the present invention.

FIGS. 4-6 provide insight to the Psuedo-Achromatic characteristics achieved by a FIG. 3f Compensator design.

FIGS. 7a1 and 7a2 show comparison Focal Length and Spot Size respectively vs. Wavelength for single and multiple element lenses.

FIGS. 7a3 and 7a4 show typical single and dual multiple element lens system construction.

FIGS. 7a5-7a26 show possible multiple element lens constructions.

FIGS. 7a27-7a32 show possible three element lens constructions.

FIG. 8 demonstrates placing a spectroscopic ellipsometer in an environmental chamber.

DETAILED DESCRIPTION

FIGS. 1-6 show material previously disclosed in Co-Pending application Ser. No. 09/517,125, and FIGS. 7a1-7a26 show material previously disclosed in Co-Pending application Ser. No. 09/583,229. More specifically, it is noted that FIGS. 3c-3p show demonstrative designs for substantially achromatic Transmissive Compensators, and FIGS. 7a3-7a26 show demonstrative designs for substan-

tially Achromatic Multiple Element Transmissive Lenses applied in the present invention in combination.

Turning now to FIG. 1, there is shown a demonstrative spectroscopic ellipsometer system configuration. Shown are a source of polychromatic electromagnetic radiation (QTH), (eg. a quartz-halogen-lamp), a polarizer (P) a stage for supporting a sample system (STG) with a sample system (SS) present thereupon, a means (DSP) for discretely, sequentially, modifying a polarization state of a beam of electromagnetic radiation provided by said source of polychromatic electromagnetic radiation through a plurality of polarization states by passage therethrough, an analyzer (A), and a detector system (DET). (Note preferred detector systems are spectroscopic, (multi-element), such as Bucket Brigade, Diode and CCD arrays and that “off-the-shelf” spectrometer systems such as manufactured by Zeiss can also be applied). Shown also are ellipsometer electromagnetic beam in (EBI) and ellipsometer electromagnetic beam out (EBO). It is noted that said means (DSP) for discretely, sequentially, modifying a polarization state of a beam of electromagnetic radiation, while shown as present between said stage (STG) for supporting a sample system (SS) and said analyzer (A), can generally be present as (DSP') between said polarizer (P) and said stage (STG) for supporting a sample system (SS), and/or as (DSP) between said stage (STG) for supporting a sample system and said analyzer (A).

It is noted that the combination of elements (QTH), (P), and (DSP) is sometimes described as a Polarization State Generation System, and the combination of elements (DSP) (A) and (DET) is sometimes described as a Polarization State Detection System. Also, it is to be understood that the Polarization State Detection System could be rotated so as to position the Detector (DET) to detect electromagnetic radiation transmitted through the Sample (SS), and remain within the scope of the invention.

FIG. 2 shows a combined spectroscopic reflectometer/ellipsometer system wherein the source of polychromatic electromagnetic radiation (QTH), and detector (DET) system are common to both, and wherein the spectroscopic ellipsometer system is shown as being provided input and output electromagnetic beam access via fiber optics (F1) and (F2). Shown are near-normal orientation reflectometer electromagnetic beam in (EBI) and ellipsometer electromagnetic beam out (EBO). While not shown, it is noted that the source of polychromatic electromagnetic radiation (QTH), and detector (DET) system can be located distal from both the reflectometer and ellipsometer portions of the combined spectroscopic reflectometer/ellipsometer system, with fiber optics being present to interface to the reflectometer portion as well.

In both FIGS. 1 and 2, there can optionally be other (eg. focusing elements (F(E) (FE)), present on one or both sides of the sample system (SS), as shown in dashed lines. Said other elements appear ellipsometrically indistinguishable with polarization state modifiers during use. Also shown in FIGS. 1 & 2 are Compensator Rotating or Stepping Means (CSM) (CSM) for use in continuously rotating or stepwise rotating compensator (DSP) and/or (DSP) or operating means as shown in FIGS. 3a-3e. The presently disclosed invention provides that at least one focusing element ((FE) (FE')) will be present and be of multiple element construction, as discussed in conjunction with FIGS. 7a3-7a26.
FIG. 3a shows a frontal view of a discrete state polarizer (DSP) comprising an essentially circular “wheel” element (WE) with five discrete polarization state modifiers elements (A) (B) (C) (D) and (E) mounted thereupon, that said and projecting discrete polarization state modifier elements (A) (B) (C) (D) and (E) project perpendicularly to a surface thereof. FIG. 3b shows a side elevational view of a discrete state polarizer, as in FIG. 3a, oriented so that an electromagnetic beam (EMB) emerging as electromagnetic beam (EMBO) with a magnetic beam of radiation can be caused to be present. FIG. 3c shows that the Fast Axes (FAA2) & (FAB2) of said second effective Zero-Order Waveplate (ZO2) are rotated away from zero or ninety degrees, (eg. in a range around a nominal forty-five degrees such as between forty and fifty degrees), with respect to the fast axes (FAA1) & (FAB1) of said first effective Zero-Order Waveplate (ZO1). In particular FIG. 14b is a cross-sectional side view of a present invention preferred compensator (PC) constructed from a first effective zero-order plate (ZO1) which is constructed from two multiple order plates (MOA1) and (MOB1), and a second effective zero-order plate (ZO2) which is constructed from two multiple order plates (MOA2) and (MOB2). An entered electromagnetic beam (EMB1) emerges as electromagnetic beam (EMBO) with a retardation entered between orthogonal components thereof with a Retardation vs. Wavelength. FIGS. 3g and 3h are views looking into the left and right ends of the preferred present invention Compensator (PC) as shown in FIG. 3f, and show that the Fast Axes (FAA2) and (FAB2) of the second effective Zero-Order Waveplate (ZO2) are rotated away from zero or ninety degrees and are ideally oriented at forty-five degrees, with respect to the Fast Axes (FAA1) & (FAB1) of the first effective Zero-Order Waveplate (ZO1). (Note that the fast axis (FAA1) of the first effective Zero-Order Waveplate (ZO1) is shown as a dashed line in FIG. 3f, for reference). FIG. 3i demonstrates functional construction of another preferred compensator (2) which is constructed from two per se single plate Zero-Order Waveplates (MOA) and (MOB), which are typically made of materials such as mica or polymer.

(It is specifically to be understood that a present invention compensator system can be comprised of at least one Zero-Order waveplate and at least one effectively Zero-Order waveplate in combination, as well as combinations comprised of two actual Zero-Order waveplates or two effectively Zero-Order waveplates). FIGS. 3j-3p demonstrate additional compensators which can be applied in the present invention.

FIG. 3j shows that the first additional present invention retarder system (3) comprises a first triangular shaped element (P1), which as viewed in side elevation presents with first (OS1) and second (OS2) sides which project to the left and right and downward from an upper point (UP1); Said first triangular shaped element (P1) first (OS1) and second (OS2) sides have reflective outer surfaces. Said retarder system (3) further comprises a second triangular shaped element (P2) which as viewed in side elevation presents with first (IS1) and second (IS2) sides which project to the left and right and downward from an upper point (UP2), said second triangular shaped element (P2) being made of material which provides internally reflective, phase delay introducing, interfaces on first (IS1) and second (IS2) sides inside thereof. Said second triangular shaped element (P2) is oriented with respect to the first triangular shaped element (P1) such that the upper point (UP2) of said second triangular shaped element (P2) is oriented essentially vertically directly above the upper point (UP1) of said first triangular shaped element (P1). In use, an input electromagnetic beam of radiation (LB) caused to approach said first (OS1) side of said first triangular shaped element (P1) along an essentially
horizontally oriented locus, is shown as being caused to externally reflect from an outer surface thereof and travel along as electromagnetic beam of radiation (R1) which is essentially upwardly vertically oriented. Next said electromagnetic beam of radiation (R1) is caused to enter said second triangular shaped element (P2) and essentially totally internally reflect from said first (IS1) side thereof, then proceed along an essentially horizontal locus and essentially totally internally reflect from the second (IS2) side thereof and proceed along an essentially downward vertically oriented electromagnetic beam of radiation (R3). This is followed by an external reflection from an outer surface of said second side (OS2) of said first triangular shaped element (P1) such that said electromagnetic beam (LB) of radiation proceeds along an essentially horizontally oriented locus, undeviated and undisplaced from the essentially horizontally oriented locus of said input beam (LB) of essentially horizontally oriented electromagnetic radiation. This is the case even when said retarder system (3) is caused to rotate. The result of said described retarder system (3) application being that retardation is entered between orthogonal components of said input electromagnetic beam of radiation (LB). Further, said first (P1) and second (P2) triangular shaped elements are utilized, this compensator design provides inherent compensation of both angular and translational misalignments of the input light beam (LB). As well, the total retardance provided is compensated for angular misalignments of the input electromagnetic radiation beam. That is, if the input electromagnetic radiation beam (LB) is not aligned so as to form an angle of incidence of forty-five (45) degrees with the first outer surface (OS1), the reflected electromagnetic beam (R1) will internally reflect at the first internal surface (IS1) of the second triangular shaped element (P2) at a larger (smaller) angle than would be the case if said angle of incidence were forty-five (45) degrees. This effect, however, is directly compensated by a smaller (larger) angle of incidence of electromagnetic beam (R2) where it internally reflects from the inner surface (IS2) of the second triangular shaped element (P2). As another comment it is to be understood that because of the oblique angles of incidence of the reflections from the outer surfaces (OS1) and (OS2) of the first triangular shaped element (P1), a polarimeter/ellipsometer in which said compensator (3) is present will require calibration to characterize the PSI-like component thereof.

FIG. 3j2 shows a variation (3') on FIG. 3j1, wherein the first triangular shaped element is replaced by two rotateable reflecting means, identified as (OS1') and (OS2'). This modification allows user adjustment so that the locus of an entering electromagnetic beam (LB') exits undeviated and undisplaced from an entering electromagnetic beam (LB).

FIG. 3j3 shows that the second additional present invention retarder system (4) comprises a parallelogram shaped element which, as viewed in side elevation, has top (TS) and bottom sides (BS), each of length (d) parallel to one another, both said top (TS) and bottom (BS) sides being oriented essentially horizontally. Said retarder system (4) also has right (RS) and left (LS) sides parallel to one another, both said right (RS) and left (LS) sides being of length (d/cos(α)), where α is shown as an angle at which said right (RS) and left (LS) sides project from horizontal. Said retarder system (4) is made of a material with an index of refraction greater than that of a surrounding ambient. In use an input beam of electromagnetic radiation (LB) caused to enter the left side (LS) of said retarder system (4), along an essentially horizontally oriented locus, is caused to diffract inside said retarder system (4) and follow a locus which causes it to essentially totally internally reflect from internal interfaces of said third sides (HS1) and (HS2) of said second triangular shaped elements, respectively, and emerge from said right side (RS2) of said second (P2) triangular shaped
element as electromagnetic radiation beam (LB') which is oriented along an essentially horizontal locus which is undeviated and undisplaced from the essentially horizontally oriented locus of said input beam (LB) of essentially horizontally oriented electromagnetic radiation. This is the case even when said retarder system (6) is caused to rotate. The result of said described retarder system (5) application being that retardation is entered between orthogonal components of said input electromagnetic beam of radiation (LB). It is noted that as long as the third sides (H1) and (H2) of said first (P1) and second (P2) triangular shaped elements are parallel, the output electromagnetic beam (LB') is undeviated and undisplaced from the input electromagnetic beam (LB) in use. It is noted that The triangular shape elements (P1) and/or (P2) can be made of various materials with various indices of refraction, and coating(s) can be applied to one or both of the third sides (H1) and (H2) of said first (P1) and second (P2) triangular shaped elements to adjust retardation entered to an electromagnetic beam (LB1).

FIG. 3m shows that the forth additional present invention retarder system (6) comprises a triangular shaped element, which as viewed in side elevation presents with first (LS) and second (RS) sides which project to the left and right and downward from an upper point (UP). Said retarder system (6) further comprises a third side (H) which is oriented essentially horizontally and which is continuous with, and present below said first (LS)— and second (RS) sides. Said retarder system (6) is made of a material with an index of refraction greater than that of a surrounding ambient. In use an input beam of electromagnetic radiation (LB) caused to enter the first (LS) side of said retarder system (6) along an essentially horizontally oriented locus, is caused to diffracted inside said retarder system (6) and follow a locus which causes it to essentially totally internally reflect from internal interfaces of both said top and bottom (PA1) and second (PA2) vertically oriented side of the second parallelogram shaped element (PA2). In use an input beam of electromagnetic radiation (LB) caused to enter an essentially vertically oriented side (RS1) in the present invention Berek-type retarder system (7) application being that retardation is entered between orthogonal components of said input electromagnetic beam of radiation (LB).

FIG. 3n shows that the fifth additional present invention retarder system (7) comprises first (PA1) and second (PA2) parallelogram shaped elements which, as viewed in side elevation, each have top (TS1) and bottom (BS1) sides parallel to one another, both said top (TS1) and bottom (BS1) sides being oriented at an angle to horizontal. Said first (PA1) and second (PA2) parallelogram shaped elements each have right (RS1) and left (LS1) sides parallel to one another, all said right (RS1) and left (LS1) sides being oriented essentially vertically. Said first (PA1) and second (PA2) parallelogram shaped elements are made of material with an index of refraction greater than that of a surrounding ambient. As long as the third side (H1) of the retarder system (6) is caused to rotate, the result of said described retarder system (7) application being that retardation is entered between orthogonal components of said input electromagnetic beam of radiation (LB).

\[ d = \frac{1}{\sin(\alpha)} + \tan(\phi) \]

in conjunction with the index of refraction (n) of the material from which the retarder system (6) is made, and the locus of the input electromagnetic radiation beam (LB) is parallel with the third side (H) of said retarder system (6), the output electromagnetic beam (LB') will not be deviated or translated with respect to the input electromagnetic beam (LB). As well, the dashed line (DL) below the upper point (UP). This indicates that as the region above said dashed line (DL) is not utilized, the portion of said retarder system (6) thereabove can be removed. It is also noted that the input electromagnetic beam (LB) enters and exits the retarder system (6) other than along a normal to a surface thereof, said retarder system is not an ideal retarder with a PSI of forty-five (45) degrees. It is noted that the third side (H) of the retarder system (6) can be coated to change the retardation effects of an internal reflection of an electromagnetic beam of radiation therefrom, and such a coating can have an adverse effect on the nonideal PSI characteristics.

FIG. 3p shows that the fifth additional present invention retarder system (7) comprises first (PA1) and second (PA2) parallelogram shaped elements which, as viewed in side elevation, each have top (TS1)/(TS2) and bottom (BS1)/(BS2) sides parallel to one another, both said top (TS1) and bottom (BS1) sides being oriented at an angle to horizontal. Said first (PA1) and second (PA2) parallelogram shaped elements each have right (RS1)/(RS2) and left (LS1)/(LS2) sides parallel to one another, all said right (RS1) and left (LS1) sides being oriented essentially vertically. Said first (PA1) and second (PA2) parallelogram shaped elements are made of material with an index of refraction greater than that of a surrounding ambient. As long as the third side (H1) of the retarder system (6) is caused to rotate, the result of said described retarder system (7) application being that retardation is entered between orthogonal components of said input electromagnetic beam of radiation (LB).
magnetic beams input thereto. Also, said retarder system (8) through both of said first polarized beam of electromagnetic radiation (LB') passing
through is determined by a tipping of said plate. The retardation introduced to an electromagnetic beam caused to transmit therethrough is determined by a tipping of said plate. The retardation system (8) having two such Berek-type retarders emerges from the second thereof in a polarized state with a phase angle of approximately 90 degrees. This retardation characteristic is very nearly ideal in that the PSI component of the retarder is insensitive to small angular deviations.

A variation of the just described retarder system (8) applies to the seventh additional present invention retarder system (9) as well, with the difference being that a FIG. 302 offset angle PHI (Φ) other than zero (0.0) is present between fast axes of the two Berek-type plates. The description of the system remains otherwise unchanged. The benefit derived, however, is that a flatter than (1/wavelength) retardation characteristic can be achieved thereby.

FIG. 301 serves as the pictorial reference for the eighth additional present invention retarder system (10) which comprises first (BK1), second (BK2), third (BK3) and forth (BK4) Berek-type retarders which each have an optical axes essentially perpendicular to a surface thereof, each of which first (BK1) and second (BK2) Berek-type retarders has a fast axis, said fast axes in said first (BK1) and second (BK2) Berek-type retarders being oriented essentially parallel to one another. This is exemplified by FIG. 302a. Said first (BK1) Berek-type retarder presents with first (LS1) and second (RS1) essentially parallel sides and said second (BK2) Berek-type retarders each present with first (LS2) and second (RS2) essentially parallel sides, and said first (BK1) and second (BK2) Berek-type retarders are oriented, as viewed in side elevation, with first (LS1) and second (RS1) sides of said first Berek-type retarder being oriented other than parallel to first (LS2) and second (RS2) sides of said second (BK2) Berek-type retarder. In use an incident beam of electromagnetic radiation (LB) is caused to impinge upon said first (BK1) Berek-type retarder on said first side (LS1) thereof, partially transmit therethrough then impinge upon the second (BK2) Berek-type retarder, on said first (LS2) side thereof, and partially transmit therethrough then impinge a third (BK3) Berek-type retarder being oriented other than parallel to first (LS3) and second (RS3) sides of said forth (BK4) Berek-type retarder; such that in use an incident beam of electromagnetic radiation (LB) exiting said second (BK2) Berek-type retarder is caused to impinge upon said third (BK3) Berek-type retarder on said first (LS3) side thereof, partially transmit therethrough then impinge upon said forth (BK4) Berek-type retarder on said first (LS4) side thereof, and partially transmit therethrough such that a polarized beam of electromagnetic radiation (LB') passing through said first (BK1), second (BK2), third (BK3) and forth (BK4) Berek-type retarders emerges from the forth (BK4) Berek-type retarder in a polarized state with a phase angle between orthogonal components therein which is different than that in the incident beam of electromagnetic radiation (LB) caused to impinge upon the first (LS1) side of said first (BK1) Berek-type retarder, in a direction which is an essentially undeviated and undisplaced from said incident beam of electromagnetic radiation (LB). This is the case even when said retarder system (8) is caused to rotate. The result of said described retarder system (8) application being that retardation is entered between orthogonal components of said input electromagnetic beam of radiation.

A ninth additional present invention retarder system (11) is also pictorially represented by FIG. 301a and is similar to that just described excepting that the Berek-type retarder plates (BK1) and (BK2) fast axes need not be parallel to one another and the Berek-type retarder plates (BK3) and (BK4) need not be parallel to one another. However, if as a group Berek-type retarder plates (BK1) and (BK2) and (BK3) and (BK4) are parallel, they can be, but need not be parallel the fast axes of Berek-type retarder plates (BK1) and (BK2) and (BK3) and (BK4). This embodiment includes the case where all the fast axes of all Berek-type retarders (BK1), (BK2), (BK3) and (BK4) are all different.

Turning now to FIG. 303a, it is shown that the present invention system source of polychromatic radiation (QTH) as in FIG. 1, can, but not necessarily, be a system for providing an output beam (OB) of polychromatic electromagnetic radiation which has a relatively broad and flattened intensity vs. wavelength characteristic over a wavelength spectrum (generally identified as (LS)), said output beam (OB) of polychromatic electromagnetic radiation substantially being a comingle composite of a plurality of input beams, (IB1) and (IB2), of polychromatic electromagnetic radiation which individually do not provide as relatively broad and flattened a intensity vs. wavelength characteristic over said wavelength spectrum, as does said output comingle composite beam of polychromatic electromagnetic radiation, said system for providing an output beam of polychromatic electromagnetic radiation which has a relatively broad and flattened intensity vs. wavelength characteristic over a wavelength spectrum comprising:

a. at least a first (Sl) and a second (S2) source of polychromatic electromagnetic radiation, (IB1) and (IB2) respectively; and
b. at least one electromagnetic beam combining (BCM) means comprising an uncoated plate, (eg. uncoated fused silica or glass etc. such that transmission characteristics thereof are determined by angle-of-incidence and polarization state of a beam of electromagnetic radiation).

The at least one electromagnetic beam combining means (BCM) is positioned with respect to said first (S1) and second (S2) sources of polychromatic electromagnetic radiation, (IB1) and (IB2) respectively, such that a beam of polychromatic electromagnetic radiation (IB1) from said first (S1) source of polychromatic electromagnetic radiation passes through said at least one electromagnetic beam combining means (BCM), and such that a beam of polychromatic electromagnetic radiation (IB2) from said second (S2) source of polychromatic electromagnetic radiation reflects from said at least one electromagnetic beam combining means (BCM) and is comingled with said beam of polychromatic electromagnetic radiation (IB1) from said first source (S1) of polychromatic electromagnetic radiation which passes through said at least one electromagnetic beam combining means (BCM). The resultant beam of polychromatic electromagnetic radiation (OB) is substantially an output beam of polychromatic electromagnetic radiation which has a relatively broad and flattened intensity vs. wavelength over a wavelength spectrum, comprising said comingled composite of a plurality of input beams of polychromatic electromagnetic radiation which individually do not provide such a relatively broad and flattened intensity vs. wavelength over a wavelength spectrum characteristic.

Further, as described in the Disclosure of the Invention Section of this Specification, as the polarizer in the present invention spectroscopic ellipsometer system remains fixed in position during data acquisition, it is preferable that a source of electromagnetic radiation, and/or a present Polarizer or Polarization State Generator be positioned or configured so as to pass predominately “S” Polarized electromagnetic radiation, as referenced to said beam combining system. The reason for this is that the split between transmission and reflection “S” polarization components is less, as a function of wavelength and electromagnetic beam angle-of-incidence to said beam combining means, compared to that between the “P” components.

It is noted that any of said sources (S1) (S2) and (S3) of polychromatic electromagnetic radiation can be Xenon or Duterum, and Quartz-Halogen lamps, or other suitable source.

It is also noted that a suitable electromagnetic beam combining (BCM) means can be made of glass or a fused silica plate, (preferably uncoated), and can also be “Hot Mirrors” which reflect IR and transmit visual wavelengths, or “Cold Mirrors” which reflect visible and transmit IR; mirror-type Beamsplitters or Pellicle Beamsplitters, such as described in Edmund Industrial Optics Catalog Number N997A.

It is also generally noted that the present invention spectroscopic ellipsometer system can, but not necessarily, utilize Zeiss Diode Array Spectrometer Systems identified by manufacturer numbers in the group: (MMS1 (300–1150 nm); UV/VIS MMS (190–730 nm); UV MMS (190–400 nm); and IR MMS (900–2400 nm)) as Detector System (DE1). Said identified Zeiss systems provide a very compact system comprising a multiplicity of Detector Elements and provide focusing via a Focusing Element. Slit, and single concave holographic grating dispersive optics. However, any functional multi-element spectroscopic Detector arrangement is within the scope of the present invention.

FIGS. 4–6 are also included herein to provide insight to the Pseudo-Achromatic characteristics achieved by the FIG. 3/Compensator design. FIG. 4 shows a plot of such a compensator retardation characteristic which depends as (1/wavelength), (dashed line), as well as a present invention compensator characteristic, (solid line). The important thing to note is that a selected range of wavelengths over which a retardation of between seventy-five (75) and one-hundred-thirty (130) degrees is developed, is much greater for the present invention compensator. A present invention spectroscopic rotatable compensator ellipsometer system can com-
provides a retardation vs. wavelength characteristic retardation which individually converges a beam of electromagnetic
much

wherein at least one of said at least one hundred-thirty (130) degrees over a range of wavelengths is specifically noted that the use of liquid in a void between
length characteristics, as compared to single element Fused
lenses by showing comparison Focal Length and Spot Size
achieved by single plates with (liwavelength) retardation
consisting of in use, a beam of electromagnetic radiation sequentially
defined by a selection from the group consisting of two element of a multiple element lens can provide charac-
teristics not available where solid elements alone are
present. Where gas or liquid is present between two solid elements, it should be appreciated that it can be selected to tailor desired lens characteristics in ways not possible where a solid element is present.

Fig. 7A-7A26 show possible multiple element lens con-
structions. In a general sense the Fig. 7A5-7A22 multiple element lenses are comprised of two sequentially oriented elements, one of said two sequentially oriented elements being of a shape and orientation which individually diverges a beam of electromagnetic radiation caused to pass there-through, and the other being of a shape and orientation which individually converges a beam of electromagnetic radiation caused to pass there-through, wherein said conver-
gence effect is greater than said divergence effect; there being a region between said at least two elements such that, in use, a beam of electromagnetic radiation sequentially passes through one of said at least two elements, then said region therebetween, and then the other of said at least two elements before emerging as an effectively converged, focused, beam of electromagnetic radiation.

Fig. 7A5 shows a sequential combination of a bi-convex element and a bi-concave element.

Fig. 7A6 shows a sequential combination of a bi-concave element and a bi-convex element.

Fig. 7A7 shows a sequential combination of a bi-convex element and a plano-concave element with said concave side of said plano-concave element adjacent to said bi-convex element.

Fig. 7A8 shows a sequential combination of a bi-convex element and a plano-concave element with said essentially flat side of said plano-concave element being adjacent to said bi-convex element.

Fig. 7A9 shows a sequential combination of a plano-
concave element and a bi-convex element with said essentially flat side of said plano-concave element adjacent to said bi-convex element.

Fig. 7A10 shows a sequential combination of a plano-
concave element and bi-convex element with the concave
side of said plano-concave element adjacent to said bi-
convex element.

Fig. 7A11 shows a sequential combination of a plano-
convex element and a bi-convex element with said essentially flat side of said plano-convex element adjacent to said bi-convex element.

Fig. 7A12 shows a sequential combination of a bi-
concave element with a plano-convex element with said convex side of said plano-convex element adjacent to said bi-concave element.

Fig. 7A13 shows a sequential combination of a plano-
concave element and a plano-convex element with the essentially flat side of said plano-concave element being adjacent to the convex side of the plano-convex element.

Fig. 7A14 shows a sequential combination of a plano-
concave element and a plano-convex element with the essentially flat side of said plano-concave element being adjacent to the flat side of said plano-convex element.

Fig. 7A15 shows a sequential combination of a plano-
convex element and a plano-convex element with the essentially flat side of said plano-convex element and the essentially flat side of said plano-concave element being adjacent to one another.
FIG. 7a16 shows a sequential combination of a plano-concave element and a plano-convex element with the concave side of said plano-concave element being adjacent to the convex side of the plano-convex element. FIG. 7a17 shows a sequential combination of a plano-convex element bi-concave element with said convex side of said plano-convex element adjacent to said bi-concave element.

FIG. 7a18 shows a sequential combination of a bi-concave element and a plano-convex element with said essentially flat side of said plano-convex element adjacent to said bi-concave element.

FIG. 7a19 shows a sequential combination of a plano-convex element and a plano-convex element with said convex side of said plano-convex element adjacent to the concave side of the plano-convex element.

FIG. 7a20 shows a sequential combination of a plano-concave element and a plano-convex element with said essentially flat side of said plano-convex element being adjacent to the essentially convex side of the plano-convex element.

FIG. 7a21 shows a sequential combination of a plano-convex element and a plano-convex element with said convex side of said plano-convex element being adjacent to the essentially flat side of the plano-convex element.

FIG. 7a22 shows a sequential combination of a plano-concave element with a plano-convex element with the essentially flat side of said plano-convex element being adjacent to the concave side of said plano-convex element.

FIG. 7a23 shows that multiple element lens systems can be a sequence of at least two sequentially oriented elements characterized by being a selection from the group consisting of:

- comprising a sequential combination of a converging (C) element and a diverging (D) element;
- comprising a sequential combination of a diverging (D) element and a converging (C) element;
- comprising a sequential combination of a converging element (C), a diverging element (D), a converging element (C) and a diverging element (D);
- comprising a sequential combination of a converging element (C), a diverging (D) element, a diverging (D), element and a converging (C) element;
- comprising a sequential combination of a converging element (D), a converging element (C), a diverging (D) element and a converging (C) element;
- comprising a sequential combination of a diverging element (D), a converging element (C), a converging element (C) and a diverging (D) element.

And, of course, other sequential lens element configurations within the scope of the present invention include:

- Converging (C), Diverging (D), Converging (C);
- Converging (C), Converging (C), Diverging (D);
- Diverging (D), Diverging (D), Converging (C);
- Converging (C), Diverging (D), Diverging (D);
- Diverging (D), Diverging (D), Converging (C);
- Diverging (D), Converging (C), Converging (C);
- Converging (C), Converging (C), Diverging (D), Diverging (D);
- Diverging (D), Diverging (D), Converging (C), Converging (C).

FIGS. 7a27–7a32 show three element lens constructions. It is noted that multiple element lenses can include a converging element selected from the group consisting of:

- a positive miniscus;
- an asymmetric convex;
- and/or a diverging element selected from the group consisting of:
  - a negative miniscus;
  - an asymmetric concave;
  - where miniscus refers to a bi-concave element wherein the radius of curvature is different for the two concave aspects thereof.

It is specifically noted that while the lenses shown in FIGS. 7a3, 7a4 and 7a5–7a26 are typically selected to demonstrate radial symmetry, it is within the scope of the present invention to utilize non-radially symmetric lenses, where, for instance, a spot size length to width aspect ratio is to be modified thereby. Therefore any lens shown or indicated in FIGS. 7a3, 7a4 and 7a5–7a26 can be designed to demonstrate radial symmetry, or non-radial symmetry, or be of any other functional type, where the achrmonic properties are present.

FIG. 8 is included to disclose that the presently disclosed spectroscopic polarimeter can be contained within a Chamber (CH) System for controlling the ambient atmosphere. Possible Chamber configurations are:

- it comprises at least one chamber region in which is present polarization state generator (PSG) comprising component(s) prior to said material system (SS), said material system (SS), and polarization state detector (PSD) comprising component(s) after said material system (SS);
- it comprises at least three chamber regions, in one of which is present polarization state generator (PSG) comprising component(s) prior to said material system (SS), in the second of which is present the material system (SS) and in the third of which is present polarization state detector (PSD) comprising component(s) after said material system (SS);
- it comprises at least two chamber regions, in one of which is present polarization state generator (PSG) comprising component(s) prior to said material system (SS) and said material system (SS), and in the second of which is present polarization state detector (PSD) comprising component(s) after said material system (SS);
- it comprises at least two chamber regions, in one of which is present polarization state generator (PSG) comprising component(s) prior to said material system (SS), and in the second of which is present polarization state detector (PSD) comprising component(s) after said material system (SS) and said material system (SS); and
- where the combination of elements (QTH), (P), and (DSP) in FIG. 1 is described as a Polarization State Generation System (PSG), and the combination of elements (DSP) (A) and (DET) is described as a Polarization State Detection System (PSD).

It is noted that the terminology Polarizer (P), Analyzer (A), Compensator (C) include any element which performs the desired function.

Finally, it is to be understood that the terminology “spectroscopic ellipsometer is to be read with sufficient breadth to include spectroscopic polarimeter and the like systems.

Having hereby disclosed the subject matter of the present invention, it should be obvious that many modifications, substitutions, and variations of the present invention are possible in view of the teachings. It is therefore to be understood that the invention may be practiced other than as specifically described, and should be limited in its breadth and scope only by the Claims.
We claim:
1. A system for monitoring change in:
   the intensity of; and/or
   the ratio of and/or
   the phase between orthogonal components in;
   a spectroscopic beam of electromagnetic radiation which is
   caused by interaction with a material system;
   said system comprising at least one lens which is of multiple
   element construction and positioned so that beam of elec-
   tromagnetic radiation transmits therethrough, wherein, at
   least two elements thereof are made from different materials,
   such that in use the focal length for each wavelength in a
   range of wavelengths is within an acceptable range of focal
   lengths;
   said at least one multiple element lens being characterized
   by at least one selection from the group consisting of:
   a) the focal length is between forty and forty-one
      millimeters over a range of wavelengths of at least
      two-hundred to seven-hundred nanometers;
   b) the focal length varies by less than five (5%) percent
      over a range of wavelengths of between two-hundred
      and five-hundred nanometers; and
   c) the spot diameter at the focal length is less than
      seventy-five microns over a range of wavelengths of
      at least two-hundred to seven-hundred nanometers;
   said system further comprising at least one compensator
   positioned so that beam of electromagnetic radiation trans-
   mits therethrough, said compensator being characterized by
   a selection from the group consisting of:
   said at least one compensator produces a retardance of
   between seventy-five (75) and one-hundred-thirty
   (130) degrees over a range of wavelengths defined by
   a selection from the group consisting of:
   a) between one-hundred-ninety (190) and seven-hun-
      dred-fifty (750) nanometers;
   b) between two-hundred-forty-five (245) and nine-
      hundred (900) nanometers;
   c) between three-hundred-eighty (380) and seventeen-
      hundred (1700) nanometers;
   d) within a range of wavelengths defined by a maxi-
      mum wavelength (MAXW) and a minimum wave-
      length (MINW) wherein the ratio of (MAXW)/
      (MINW) is at least one-and-eight-tenths (1.8); and
   said at least one compensator produces a retardation
   between thirty (30.0) and less than one-hundred-thirty-
   five (135) degrees over a range of wavelengths speci-
   fied from MINW to MAXW by a selection from the
   group consisting of:
   a) MINW less than/equal to one-hundred-ninety (190)
      and MAXW greater than/equal to one-thousand
      (1000) nanometers;
   b) MINW less than/equal to two-hundred-twenty (220)
      and MAXW greater than/equal to one-thousand
      (1000) nanometers.
   c) within a range of wavelengths defined by a maxi-
      mum wavelength (MAXW) and a minimum wave-
      length (MINW) range where (MAXW)/ (MINW) is
      at least four-and-one-half (4.5).
2. A system as in claim 1, in which said at least one
   multiple element lens demonstrates birefringence.
3. A system as in claim 1, in which said at least one
   multiple element lens comprises at least two elements which
   are made from different materials independently selected
   from the group consisting of:
   CaF₂;
   BaF₂;
   LiF;
   MgF₂;
   fused silica;
   a void region;
   a liquid filled region; and
   a functional equivalent to a void region.
4. A system as in claim 1 in which, during data collection,
   said at least one compensator is caused to perform motion
   selected from the group consisting of:
   continuously rotates; and
   sequentially rotates through a plurality of discrete angles;
   around an axis defined by the locus of the spectroscopic
   electromagnetic beam as it transmits therethrough.
5. A system as in claim 1 which is present in a Chamber
   configured as a selection from the group consisting of:
   it comprises at least one chamber region in which is
   present polarization state generator comprising compon-
   ent(s) prior to said material system, said material
   system, and polarization state detector comprising compo-
   nent(s) after said material system;
   it comprises at least three chamber regions, in one of
   which is present polarization state generator compris-
   ing component(s) prior to said material system, in the
   second of which is present material system and in the
   third of which is present polarization state detector
   comprising component(s) after said material system;
   it comprises at least two chamber regions, in one of which
   is present polarization state generator comprising compo-
   nent(s) prior to said material system and said mate-
   rial system, and in the second of which is present polar-
   ization state detector comprising component(s) after
   said material system;
   it comprises at least two chamber regions, in one of which
   is present polarization state generator comprising compo-
   nent(s) prior to said material system, and in the
   second of which is present polarization state detector
   comprising component(s) after said material system and
   said material system.
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