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## Hyper-spectral multi-spot optical reflectometer

### Abstract

An optical reflectometry system, including a processing chamber, a substrate support wherein the substrate support is configured to accept a substrate, a light source configured to transmit an incident light beam, an optical fiber bundle coupled to the light source and optically coupled to a lens assembly, wherein the lens assembly optically coupled to at least a first optical fiber, and configured to transmit to, and receive from, at least one area of the substrate through the transparent window, an optical splitter disposed within the optical fiber bundle; a return fiber bundle coupled to the optical splitter, and coupled to a detection system, wherein the detection system is configured to reference a reference light beam to a reflected light beam to improve a signal-to-noise ratio, analyze a full spectrum of the reflected light beam, and determine at least one characteristic of the at least one area of the substrate.

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## Background/Summary

BACKGROUND

Field

(1) Embodiments of the present disclosure generally relate to improvements in optical reflectometry for substrate processing systems.

Description of the Related Art

(2) Semiconductor device geometries have dramatically decreased in size since such devices were first introduced several decades ago. The increasing circuit densities have placed additional demands on processes used to fabricate semi-conductor devices. For example, as circuit densities increase, the pitch size decreases rapidly to sub 50 nm dimensions, whereas the vertical dimensions such as trench depth remain relatively constant, with the result that the aspect ratios for the features, i.e., their height divided by width, increases. The open area ratio of the device feature as a percentage of the whole wafer is getting smaller, which yields smaller percentage of light containing the information about feature. At the same time, the features tend to be deeper with a smaller opening, which reduces light coming out from the bottom of the feature, reducing the signal-to-noise (SNR) further.

(3) Precise control of the dimensions of such high density and sub-micron features is critical to the reliable formation of the semiconductor devices. Features, such as transistors and capacitors are conventionally formed in the semiconductor device by patterning a surface of a substrate to define the lateral dimensions of the features and then etching the substrate to remove material and define the features. To form features with a desired electrical performance, the dimensions of the features must be formed within control specifications. Accordingly, it may be necessary to partially remove one or more layers using a dry etching or plasma etching process. For example, for end point detection, the interference fringe pattern can be simulated for various layers and then compared during etching with the measured signal. The method is very effective and can be used to monitor

etching and end point detection of substrates with multiple layers on top.

(4) Typically, in-situ optical reflectometers use a fiber optic cable to transmit from light from the reflectometer and receive reflected light from a substrate in a substrate processing chamber. The conventional fiber optic cable can measure parameters such as film quality, film thickness, or a width of structures on a substrate. However, due to the large distance between the lens and the substrate being processed, the effective beam size at the substrate ranges from a few millimeters to over 10 millimeters. The large beam size makes it difficult to focus the beam on the wafer, and the reflected beam contains information from many features on the substrate that are not of interest. This makes target features of interest hard to identify and filter. Accordingly, there is need in the art for improvements to in-situ optical reflectometers.

SUMMARY

(5) Embodiments of the present disclosure generally relate to improvements in optical reflectometry for substrate processing systems.

(6) One general aspect includes an optical reflectometry system. The optical reflectometry system also includes a processing chamber having a ceiling, sidewalls, and a bottom defining an internal volume, where the ceiling contains a transparent window. The system also includes a substrate support located in the internal volume, where the substrate support is configured to accept a substrate. The system also includes a light source located outside of the internal volume configured to transmit an incident light beam. The system also includes an optical fiber bundle located outside of the internal volume may include at least a first optical fiber coupled to the light source and optically coupled to a lens assembly, where the lens assembly is disposed above the transparent window, and optically coupled to at least a first optical fiber, and configured to: transmit to at least one area of the substrate through the transparent window, receive from the at least one area of the substrate through the transparent window; an optical splitter disposed within the optical fiber bundle. The system also includes a return fiber bundle may include at least a first return fiber coupled to the optical splitter and coupled to a detection system, where the detection system is configured to: reference a reference light beam and a reflected light beam to improve a signal-to-noise ratio (snr) for analysis of the reflected light beam, analyze a full spectrum of the reflected light beam, and determine at least one characteristic of the at least one area of the substrate based upon the analysis of the full spectrum of the reflected light beam. Other embodiments of this aspect include corresponding computer systems, apparatus, and computer programs recorded on one or more computer storage devices, each configured to perform the actions of the methods.

(7) One general aspect includes a method of optical reflectometry. The method also includes transmitting, via an optical fiber bundle may include at least a first optical fiber, an incident light beam from a light source to an optical splitter. The method also includes transmitting a first portion of the incident light beam, via the optical fiber bundle, from the optical splitter to a lens assembly. The method also includes transmitting a second portion of the incident light beam as a reference light beam, via a return fiber bundle may include a plurality of return fibers, from the optical splitter to a detection system. The method also includes focusing the first portion of the incident light beam as rays of incident light from the lens assembly upon at least one area of a substrate disposed within a processing chamber. The method also includes receiving rays of reflected light from the at least one area of the substrate at the lens assembly. The method also includes transmitting the rays of reflected light as a reflected light beam from the lens assembly, via the optical fiber bundle, to the optical splitter. The method also includes transmitting the reflected light beam from the optical splitter, via the return fiber bundle, to the detection system. The method also includes determining at least one characteristic of the at least one area of the substrate. Other embodiments of this aspect include corresponding computer systems, apparatus, and computer programs recorded on one or more computer storage devices, each configured to perform the actions of the methods.

# Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only exemplary embodiments and are therefore not to be considered limiting of its scope, and may admit to other equally effective embodiments.

(2) FIG. **1** is a schematic cross sectional view of an example plasma processing chamber having a detection system, in accordance with one example of the disclosure.

(3) FIG. **2** is an example schematic cross sectional view of a collimated optical path with an optical fiber bundle configured to transmit and receive light in a processing chamber, as commonly employed in the prior art

(4) FIG. **3** is an example schematic cross sectional view of an optical path of a single optical fiber configured to transmit and receive light in the processing chamber, in accordance with one example of the disclosure.

(5) FIG. **4** is a schematic cross sectional view of a fiber bundle design and optical path with an optical fiber bundle configured to transmit and receive light in a processing chamber, in accordance with one example of the disclosure.

(6) FIG. **4**A is a cross-sectional view of the exit of an optical fiber bundle configured to transmit and receive light in a processing chamber, in accordance with one example of the disclosure.

(7) FIG. **4**B is an example cross-sectional view of the light beams transmitted from a plurality of optical fibers, as received, and reflected at the surface of substrate, in accordance with one example of the disclosure.

(8) FIG. **5**A illustrates a graph of single wavelength referencing, in accordance with one example of the disclosure.

(9) FIG. **5**B illustrates a graph of multiple wavelength referencing, in accordance with one example of the disclosure.

(10) FIG. **6** is a flow diagram of a method for emitting and collecting reflected light within a processing chamber, in accordance with one example of the disclosure.

(11) To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

DETAILED DESCRIPTION

(12) Examples of the present disclosure generally relate to improvements in optical reflectometry for substrate processing systems.

(13) FIG. **1** is a schematic cross sectional view of an example processing chamber **100** from a substrate processing system, having a detection system **164**, in accordance with one example of the disclosure. Suitable processing chambers include inductively and capacitive coupled plasma etch chambers such as the TETRA® photomask etch system and the SYM3® etch system, both available from Applied Materials, Inc., of Santa Clara, California, among others. Other types of processing chambers may be adapted to benefit from the invention, including, for example, capacitive coupled parallel plate chambers, and magnetically enhanced ion etch chambers, as well as inductively coupled plasma etch chambers.

(14) The processing chamber **100** includes a chamber body **102** and a ceiling **103** that is energy transparent, i.e., enabling energy and light to be transmitted therethrough. The chamber body **102**, has sidewalls, a ceiling **103**, and also has a chamber bottom **107**. The chamber body **102**, sidewalls,

ceiling **103**, and chamber bottom **107** define an internal volume of the processing chamber **100**. The chamber body **102** is fabricated from a metal, such as anodized aluminum or stainless steel. The ceiling **103** is mounted on the chamber body **102**. The ceiling **103** may be flat, rectangular, arcuate, conical, dome, or multi-radius shaped. The ceiling **103** is fabricated from an energy transparent material such as a ceramic or other dielectric material. An inductive coil **126** is disposed over the ceiling **103** of the processing chamber **100**, and is utilized to energize gases within the processing chamber **100** during processing.

(15) A substrate support **116** is disposed in the processing chamber **100** having a substrate support surface **188** to support a substrate **120** during processing. The substrate support **116** may include an electrostatic chuck, with at least a portion of the substrate support **116** being electrically conductive and capable of serving as a process bias cathode.

(16) Processing gases are introduced into the processing chamber **100** from a process gas source **148** through a gas distributor **122**. The gas distributor **122** may be disposed in the ceiling **103** or chamber body **102**, above the substrate support **116**. Mass flow controllers (not shown) for each processing gas, or alternatively, for mixtures of the processing gas, are disposed between the gas distributor **122** and the process gas source **148** to regulate the respective flow rates of the process gases into the chamber body **102**.

(17) An interior volume **114** is defined in the chamber body **102** between the substrate support **116** and the ceiling **103**. A plasma is formed in the interior volume **114** from the processing gases using a coil power supply **127** which supplies power to the inductive coil **126** to generate an electromagnetic field in the interior volume **114** through an RF match network **135**. The substrate support **116** may include an electrode disposed therein, which is powered by an electrode power supply **125** and generates a capacitive electric field in the processing chamber **100** through an RF match network **128**. RF power is applied to the electrode in the substrate support **116** while the chamber body **102** is electrically grounded. The capacitive electric field is transverse to the plane of the substrate support **116**, and influences the directionality of charged species more normal to the substrate **120** to provide more vertically oriented anisotropic etching of the substrate **120**.

(18) Process gases and etchant byproducts are exhausted from the processing chamber **100** through an exhaust system **130**. The exhaust system **130** may be disposed in the chamber bottom **107** of the processing chamber **100** or may be disposed in another portion of the chamber body **102** of the processing chamber **100** for removal of processing gases. A throttle valve **132** is provided in an exhaust port **134** for controlling the pressure in the processing chamber **100**.

(19) FIG. **1** further illustrates the optical fiber bundle **104** configured to detect features within or on a substrate **120** disposed in a processing chamber **100**. The optical fiber bundle **104** has a diameter of about 0.05 mm to about 2 mm. For example, the optical fiber bundle **104** has a diameter of about 1 mm. The optical fiber bundle **104** is included in a detection system **164**, in one example. The detection system **164** may be an optical reflectometry system. For example, a spectroscopic reflectometry system configured to process an input channel and determine one or more characteristics of the substrate disposed in the processing chamber. For example, the detection system **164** may be an interferometer endpoint detection system configured to process an input channel and determine one or more characteristics of the substrate disposed in the processing chamber **100**. In one example, which may be combined with other examples, the detection system **164** is capable of simultaneously processing a number of input channels. For instance, the detection system **164** is capable of simultaneously processing between about 1 input channel and about 20 input channels. For instance, the detection system **164** is capable of simultaneously processing between about 10 input channels and about 50 input channels. For instance, the detection system **164** is capable of simultaneously processing between about 10 input channels.

(20) In one example, which may be combined with other examples, the detection system **164** is capable of switching between banks (not shown) of input channels to measure additional areas of substrate **120**. For instance, the detection system **164** may include a number of banks, each with a

number of input channels. For instance, the detection system **164** may include between about 1 bank and about 20 banks. For instance, the detection system **164** may include between at least 1 bank and about 20 banks. For instance, the detection system **164** may include 10 banks. Each bank includes a number of input channels. For instance, each bank includes between about 1 input channel and about 20 input channels. For instance, each bank includes between about 10 input channels and about 50 input channels. For instance, each bank includes between about 10 input channels.

(21) In one example, which may be combined with other examples, the detection system **164** determines one or more characteristics, such as a dimension of a feature, height of feature, radiant emissions of the plasma, changes in plasma characteristics, or similar, of the substrate to determine the endpoint of one or more stages of an etching process. The endpoint of an etching stage may occur, for example, when a layer of the substrate **120** has been sufficiently removed, or etched through to reveal an underlying layer. In another example, the endpoint of the etching state can occur when a desired dimension, such as a desired height of a feature, has been obtained. Determination of the endpoint of the etching stage allows for etching of the substrate **120** to be halted once a stage has been completed, thus reducing the occurrence of over-etching or under-etching of the substrate **120**. The endpoint of one or more of the stages may be determined by monitoring radiation emissions from plasma in the processing chamber **100**, the plasma emitting radiation that changes in intensity and wavelength according to a change in the composition of the energized gas. For example, a change in composition of the energized gas can arise from the etching through of an overlying layer to expose an underlying layer on the substrate **120**. As such, the detection system **164** monitors the one or more characteristics of the radiation emissions to determine the extent of etching of the substrate or other conditions in the process chamber **100**.

(22) The features of one or more stages of substrate processing of the processing chamber **100** may be determined by the detection system **164**. In one example, the endpoint of a substrate processing stage may occur, for example, when a layer of the substrate **120** has been sufficiently removed, or etched through to reveal an underlying layer. In another example, the endpoint of the substrate processing stage can occur when a desired dimension, such as a desired height of a feature, or film thickness, has been obtained. Determination of the endpoint of the substrate processing stage allows for processing of the substrate **120** to be halted once a stage has been completed, thus reducing substrate defects. For example, the over, or under, etching of substrate **120**. The endpoint of one or more of the substrate processing stages may be determined by monitoring radiation emissions from plasma in the processing chamber **100**, the plasma emitting radiation that changes in intensity and wavelength according to a change in the composition of the energized gas. For example, a change in composition of the energized gas can arise from the etching through of an overlying layer to expose an underlying layer on the substrate **120**. As such, the detection system **164** analyzes radiation emissions to determine the extent of processing of the substrate or other conditions in the processing chamber **100**.

(23) The detection system **164** further includes a light source **166**, a lens assembly **168**, a light detector **170**, an optical splitter **172**, and a controller **150**. The light source **166** is configured to emit a light beam through optical splitter **172** and through the optical fiber bundle **104**. The light beam impinges the substrate **120** and is reflected back through the optical fiber bundle **104**. The light beam returns to the light detector **170** upon passing through the optical fiber bundle **104**, and the optical splitter **172**. For example, the lens assembly **168** is configured to focus the light beam into an incident light beam **176**. The incident light beam **176** passes through the ceiling **103** toward the substrate support surface **188** and illuminates an area or beam spot **180** on the surface **121** of the substrate **120**. In one example, which may be combined with other examples, the detection system **164** may be capable of manipulating the lens assembly **168** so that the beam spot **180** falls upon differing areas of the substrate **120** for measurement.

(24) The incident light beam **176** is reflected by the surface **121** of the substrate **120** to form a

reflected light beam **178**. At least a portion of the reflected light beam **178** is directed in a direction perpendicular to the substrate support surface **188** back through the ceiling **103**, through the optical fiber bundle **104** and optical splitter **172**, to the light detector **170**. The light detector **170** is configured to measure the intensity of the reflected light beam **178**. An exemplary light detector **170** is a spectrometer.

(25) Alternatively, the optical fiber bundle **104** can be used without the lens assembly **168**, such that the optical fiber bundle **104** is coupled directly to the ceiling **103**, having a single collimator disposed between the optical fiber bundle **104** and the ceiling **103**. For example, focusing lens **174***b* (i.e., as the collimator) can be disposed directly between the optical fiber bundle **104** and the ceiling **103**. In embodiments described herein, no collimator may be present.

(26) The light source **166** has a monochromatic or polychromatic light source that generates the incident light beam **176** used to illuminate the beam spot **180** on the substrate **120**. The intensity of the incident light beam **176** is selected to be sufficiently high enough to enable the reflected light beam **178** to have a measurable intensity. In one example, the light source **166**, such as a xenon (Xe) lamp, provides a polychromatic light and generates an emission spectrum of light in wavelengths from about 200 nm to about 800 nm. The light source **166** can include a polychromatic source. The polychromatic light may be filtered to select the frequencies comprising the incident light beam **176**. Color filters can be placed in front of the light detector **170** to filter out all wavelengths except for the desired wavelength(s) of light, prior to measuring the intensity of the reflected light beam **178** entering the light detector **170**. The light source **166** can also include a monochromatic source, for example a helium-neon (He—Ne) laser, or neodymium-doped yttrium-aluminum-garnet (Nd-YAG) laser, LED, or other monochromatic light source, provides a selected wavelength of light.

(27) One or more mirrors **186**, and one or more focusing lenses, such as focusing lens **174***a*, and focusing lens **174***b* to may be used to focus the incident light beam **176** from the light source **166** to form the beam spot **180** on the surface **121** of the substrate **120**. The one or more mirrors **186**, and one or more focusing lenses, such as focusing lens **174***a*, and focusing lens **174***b* to may be used to focus the reflected light beam **178** back on an active surface of the light detector **170**. In one example, which may be combined with other examples, the one or more mirrors may be fixed mirrors, adjustable mirrors, or digital-mirror-devices (DMD). The size or area of the beam spot **180** should be sufficiently large to compensate for variations in surface topography of the substrate **120** and device design features. The size of the beam spot **180** enables detection of features and characteristics of the substrate **120**. For example, feature pitch and depth, film thickness, and other physical characteristics. The area of the reflected light beam is sufficiently large to activate a large portion of the active light-detecting surface of the light detector **170**.

(28) The incident light beam **176**, and the reflected light beam **178**, are directed through a transparent window **182** of the processing chamber **100**. The transparent window **182** allows the incident light beam **176**, and the reflected light beam **178**, to pass in and out of the processing environment of the processing chamber **100**. The substrate support surface **188** of the substrate support **116** on which the substrate **120** rests is disposed parallel to the ceiling **103**. In one example, the transparent window **182** is located in the ceiling **103** of the processing chamber **100**, oriented relative to the substrate **120** and the substrate support **116**. The transparent window **182** is configured to receive an incident light beam from the detection system **164**. The transparent window **182** enables transmission of the incident light beam **176** to the substrate. The transparent window **182** also enables the reflected light beam **178** to pass therethrough upon reflection from the substrate **120**. The transparent window **182** is further configured to transmit the reflected light beam **178** to the detection system **164**.

(29) The controller **150** is electrically coupled to the detection system **164**, including light detector **170**, controller **150**, and the light source **166** via a wire **158**. The controller **150** calculates portions of the real-time measured waveform spectra of reflected light beam **178** reflected from the beam

spot **180** on substrate **120** and processes the spectra by using advanced spectral analysis techniques, including comparing the spectra with stored characteristic waveform patterns. In one example, which may be combined with other examples, the controller **150** calculates and adjusts the position and orientation of the lens assembly **168**.

(30) The controller **150** includes a programmable central processing unit (CPU) **152** which is operable with a memory **154** (e.g., non-volatile memory) and support circuits **156**. The support circuits **156** are conventionally coupled to the CPU **152** and comprise cache, clock circuits, input/output subsystems, power supplies, and the like, and combinations thereof coupled to the various components of the processing chamber **100**, to facilitate control thereof.

(31) The CPU **152** is one of any form of general purpose computer processor used in an industrial setting, such as a programmable logic controller (PLC), for controlling various components and sub-processors of the processing system. The memory **154**, coupled to the CPU **152**, is non-transitory and is typically one or more of readily available memories such as random access memory (RAM), read only memory (ROM), floppy disk drive, hard disk, or any other form of digital storage, local or remote.

(32) Typically, the memory **154** is in the form of a non-transitory computer-readable storage media containing instructions (e.g., non-volatile memory), which when executed by the CPU **152**, facilitates the operation of the processing chamber **100**. The instructions in the memory **154** are in the form of a program product such as a program that implements the methods of the present disclosure. The program code may conform to any one of a number of different programming languages. In one example, the disclosure may be implemented as a program product stored on computer-readable storage media for use with a computer system. The program(s) of the program product define functions of the embodiments (including the methods described herein).

(33) Illustrative non-transitory computer-readable storage media include, but are not limited to: (i) non-writable storage media (e.g., read-only memory devices within a computer such as CD-ROM disks readable by a CD-ROM drive, flash memory, ROM chips or any type of solid-state non-volatile semiconductor memory devices, e.g., solid state drives (SSD)) on which information may be permanently stored; and (ii) writable storage media (e.g., floppy disks within a diskette drive or hard-disk drive or any type of solid-state random-access semiconductor memory) on which alterable information is stored. Such computer-readable storage media, when carrying computer-readable instructions that direct the functions of the methods described herein, are embodiments of the present disclosure. In some embodiments, the methods set forth herein, or portions thereof, are performed by one or more application specific integrated circuits (ASICs), field-programmable gate arrays (FPGAs), or other types of hardware implementations. In some other embodiments, the substrate processing and/or handling methods set forth herein are performed by a combination of software routines, ASIC(s), FPGAs and, or, other types of hardware implementations. One or more controllers **150** may be used with one or any combination of the various systems described herein.

(34) FIG. **2** is an example schematic cross sectional view of a collimated optical path with an optical fiber configured to transmit and receive light in a processing chamber, as commonly employed in the prior art.

(35) An incident light beam **176**, originating at the light source **166**, is collected by the optical fiber bundle **104**. The incident light beam is received by an optical splitter **172**. In some examples, the optical splitter **172** is disposed along the length of the optical fiber bundle **104**. In other examples, the optical splitter **172** may be disposed at the light source **166**. The incident light beam **176** originating from the light source **166**, passes through the optical splitter **172** and exits the optical fiber bundle **104** at the fiber bundle exit **264**. The fiber bundle exit **264** is positioned above the lens assembly **168**, which includes a lens acting as a collimator. The incident light beam **176** has an initial spot size approximately equal to the optical fiber diameter. For example, the initial spot size **260** may be around 100 micrometers (μm) in diameter. The incident light beam **176** exits the fiber bundle exit **264** in a spread out pattern as rays of incident light **236** each interacting with a different

portion of the lens assembly **168**. The rays of incident light **236** next pass through the lens assembly **168** where the rays of incident light **236** are collimated and transmitted toward the substrate **120**. After impinging the substrate **120**, the rays of incident light **236**, are reflected back toward the optical fiber bundle **104** as rays of reflected light **240**.

(36) Due to the space constraints, the distance from fiber bundle exit **264** to the lens assembly **168** is usually smaller than the distance between lens assembly **168** and substrate **120** surface. This results in an amplification of the substrate image size **242** on the substrate **120** surface compared to the size of the initial spot size **260**. For example, the substrate image size **242** may be 10 millimeters (mm) in diameter. For example, the substrate image size **242** may be 100 mm in diameter. The area of the substrate image size **242** being the area to be measured by detection system **164**.

(37) After passing through the lens assembly, the rays of reflected light **240** are returned to the optical fiber bundle **104**. Collectively, the rays of reflected light **240** make up the reflected light beam **178**. The rays of reflected light **240** are then returned to the optical splitter **172**. A first portion of the reflected light beam **178** received at the optical splitter **172**, for example about 50%, is then transmitted, via the return fiber bundle **208**, to the detection system **164**.

(38) FIG. **3** is an example schematic cross sectional view of an optical path of a single optical fiber configured to transmit and receive light in the processing chamber **100** showing an improved spatial resolution on the substrate.

(39) The incident light beam **176**, emitted by the light source **166**, is received by the optical fiber bundle **104**. The optical fiber bundle **104** includes a plurality of fibers. Each fiber of the plurality of fibers of the optical fiber bundle **104** has a diameter between about 0.01 mm and 1 mm. For example, each fiber of the plurality of fibers of the optical fiber bundle **104** diameter is about 0.5 mm. The optical fiber bundle **104** transmits the incident light beam **176** and is received by an optical splitter **172**. In some embodiments, the optical splitter **172** is disposed along the length of the optical fiber bundle **104**. In other embodiments, the optical splitter **172** may be disposed at the light source **166**. In other embodiments, the optical splitter **172** may be disposed at the end of the optical fiber bundle **104**.

(40) A first portion, for example about 50%, of the received incident light beam **176** is transmitted by the optical splitter **172**, as a reference light beam **206**, through a return fiber bundle **208**, the detection system **164**. The reference light beam **206** is received by the detection system **164**, and used as a reference to reduce noise, and improve signal to noise ratio (SNR). A second portion, for example about 50%, of the received incident light beam **176** is transmitted by the optical splitter **172** and exits the optical fiber bundle **104** at the fiber bundle exit **264**.

(41) The fiber bundle exit **264** is positioned above the lens assembly **168**, shown with a fiber-to-lens distance **252**. The incident light beam **176** has an initial spot size approximately equal the diameter of a fiber of the plurality of fibers of the optical fiber bundle **104**. For example, the initial spot size **260** has a diameter between about 0.01 mm and 1 mm. For example, the initial spot size **260** diameter is about 0.5 mm. The fiber-to-lens distance **252** is about 40 millimeters (mm) to about 80 mm. For example, the fiber-to-lens distance **252** is about 50 mm.

(42) The focusing lens assembly **168** has a lens-to-substrate distance **254** from the substrate **120**. The lens-to-substrate distance **254** is based upon a ratio of the fiber-to-lens distance **252**. For example, the lens-to-substrate distance **254** ratio is between about 1:1 to about 10:1. For example, the lens-to-substrate distance **254** ratio is about 4:1. In another example, the lens-to-substrate distance **254** ratio is about 5:1.

(43) The incident light beam **176** exits the fiber bundle exit **264** in a spread out pattern as rays of incident light **236** each interacting with a different portion of the lens assembly **168**. The rays of incident light **236** next pass through the lens assembly **168** where the rays of incident light **236** are focused, but not collimated, and transmitted toward the substrate **120**.

(44) After impinging the substrate **120**, the rays of incident light **236**, are reflected back toward the

optical fiber bundle **104** as rays of reflected light **240**. Due to the space constraints, the distance from fiber bundle exit **264** to the lens assembly **168** is usually smaller than the distance between lens assembly **168** and substrate **120** surface. This results in an amplification of the substrate image size **242** on the substrate **120** surface. For example, the substrate image size **242** may be larger than the initial spot size **260** by about the ratio of lens-to-substrate distance **254** to the fiber-to-lens distance **252**. For example, the substrate image size **242** has a diameter between about 0.01 mm and 10 mm. For example, the substrate image size **242** is about 0.4 millimeters (mm) in diameter. For example, the substrate image size **242** is about 0.1 mm in diameter. For example, the substrate image size **242** is about 4 mm in diameter. As compared FIG. **2**, the optical path described herein offers a reduction in substrate image size **242**. Reducing the substrate image size **242** results in the reflected signal/spectra containing less information about non-targeted areas of the substrate, thereby increasing system sensitivity and detail resolution.

(45) The rays of reflected light **240** are returned to the lens assembly **168**. After passing through the lens assembly **168**, the rays of reflected light **240** are transmitted to the optical fiber bundle **104**. Collectively, the rays of reflected light **240** make up the reflected light beam **178**. In one example, the optical fiber bundle **104** can be concentric with the lens assembly **168**. The received rays of reflected light **240** are then transmitted to the optical splitter **172**. A first portion of the reflected light beam **178** received at the optical splitter **172**, for example about 50%, is then transmitted, via the return fiber bundle **208**, to the to the detection system **164**. A second portion of the reflected light beam **178** received at the optical splitter **172**, for example about 50%, is transmitted to the light source **166**, via the optical fiber bundle **104**.

(46) FIG. **4** is a schematic cross sectional view of a fiber bundle design and optical path with an optical fiber bundle **310** configured to transmit and receive light in a processing chamber **100** illustrating a multi-spot hyper-spectral system.

(47) Incident light beam **176**, originating at the light source **166**, is collected by the optical fiber bundle **310**. The optical fiber bundle **310** has a diameter of about 0.05 mm to about 2 mm. For example, the optical fiber bundle has a diameter of about 1 mm. The optical fiber bundle includes a plurality of optical fibers **302**. For example, an optical fiber **302***a*, an optical fiber **302***b*, an optical fiber **302***c*, and an optical fiber **302***d*. Each fiber of the plurality of optical fibers **302** has a diameter between about 0.01 mm and 1 mm. For example, the optical fibers **302** have a diameter about 0.5 mm. Each of the plurality of optical fibers **302** includes a fiber bundle exit **264**.

(48) The incident light beam **176** is transmitted by the plurality of optical fibers **302** to an optical splitter **172**. In some examples, the optical splitter **172** is disposed along the length of the optical fiber bundle **104**. In other examples, the optical splitter **172** may be disposed at the light source **166**. In one example, about 50% of the received incident light beam **176** exits through the optical splitter **172** and passes, a reference light beam **206**, through a return fiber bundle **312** comprising a plurality of return fibers **302**, to the detection system **164**. In other examples, a lower, or higher, percentage of the received incident light beam **176** exits through the optical splitter **172** and passes, as a reference light beam **206** through a return fiber bundle **312**, the detection system **164**.

(49) In one example, which may be combined with other examples, the optical splitter **172** splits the reference light beam **206** from the incident light beam **176** optically. In another example, which may be combined with other examples, the optical splitter **172** splits the reference light beam **206** from the incident light beam **176** by redirecting a portion of the plurality of fibers **302** from the optical fiber bundle **310** to the return fiber bundle **312**. In one example, which may be combined with other examples, the reference light beam **206** may be attenuated prior to being received by the detection system **164**. In one example, which may be combined with other examples, the reference light beam **206** may be attenuated by the detection system **164**. As shown, and explained below in FIG. **5**A, the reference light beam **206** is employed the detection system **164** to reduce noise and improve the signal-to-noise ratio (SNR).

(50) In another example, which may be combined with other examples, optical splitter **172** may

allow a first portion of the plurality of return fibers to each receive a sub-portion of reference light beam corresponding to an area of the light source **166**, and allow a second portion plurality of return fibers to each receive a sub-portion the reflected light beam originally corresponding to the same area of the light source. As shown, and explained below in FIG. **5**B, this allows for additional SNR improvements, or allowing SNR improvements for measurements of each area of a substrate, by the detection system **164**

(51) The remainder of the received incident light beam **176**, about 50% of the light originating from the light source **166**, passes through the optical splitter **172** and exits the optical fiber bundle **310** from the plurality of optical fibers **302** as rays of incident light **236**. For example, as rays of incident light **236** from optical fiber **302***a*, as rays of incident light **236** from optical fiber **302***b*, as rays of incident light **236** from optical fiber **302***c*, and as rays of incident light **236** from optical fiber **302***d*, all directed toward focusing lens **174***b*. In other examples, a lesser or greater percentage of the light originating from the light source **166**, passes through the optical splitter **172** and exits the optical fiber bundle **310** from the plurality of optical fibers **302** as rays of incident light **236**.

(52) The fiber bundle exit **264** of the optical fiber bundle **310** is positioned further than the focal point of the focusing lens **174***b*, illustrated as a fiber-to-lens distance **252**. The fiber-to-lens distance **252** is about 40 millimeters (mm) to about 80 mm. For example, the fiber-to-lens distance **252** is about 50 mm. The focusing lens **174***b* additionally has a lens-to-substrate distance **254** from the substrate **120**. The rays of incident light **236** pass through the focusing lens **174***b*. The rays of incident light **236** exit the focusing lens **174***b*, and contact the substrate **120** in, or about, the substrate image size **242**. The area of the substrate image size **242** formed by the rays of incident light **236** is larger than the exit of the optical fiber bundle **310**. The larger area of substrate image size **242** is generally due to space constraints. For example, the fiber-to-lens distance **252**, is typically smaller than the lens-to-substrate distance **254** resulting in an increase of the area of substrate image size **242** on the substrate.

(53) After impinging the substrate **120**, the beam reflected light **178**, as rays of reflected light **240**, is reflected back toward the optical fiber bundle **310**. The rays of reflected light **240** reflected by the substrate **120** are returned to the focusing lens **174***b*. After passing through the focusing lens **174***b*, the rays of reflected light **240** are returned to the same fiber of plurality of optical fibers **302** that the rays of incident light **236** originated from. For example, to optical fiber **302***a*, optical fiber **302***b*, optical fiber **302***c*, and optical fiber **302***d*. In other examples, which may be combined with other examples, the rays of reflected light **240** return to a different fiber of the plurality of optical fibers **302** than the fiber of the plurality of optical fibers the rays of incident light **236** originated from.

(54) The rays of reflected light **240** are then returned to the optical splitter **172**. About 50% of the reflected light beam **178** received at the optical splitter **172** is then transmitted, via the return fiber bundle **312**, to the light detector **170** of the detection system **164**. About 50% of the reflected light beam **178** received at the optical splitter **172** is then transmitted to the light source **166**, via the optical fiber bundle **310**.

(55) In one example, which may be combined with other examples, the detection system **164** is capable of measuring the multi-wavelength (wideband spectra) of the reflected light beam **178** collected by each fiber of the plurality of fibers **302**.

(56) In other examples, which may be combined with other examples, the reflected light beam **178** may be filtered, or unfiltered, attenuated, or unattenuated, and a photodiode, or charge-coupled device (CCD) employed within the detection system **164** is used measure the total power for each fiber of the plurality of fibers **302**.

(57) In other examples, which may be combined with other examples, the detection system **164**, is capable of measuring the multi-wavelength (wideband spectra) of the reflected light beam **178** collected by each fiber of the plurality of fibers **302** simultaneously. Each fiber, of the plurality of fibers **302**, transmits rays of reflected light **240** collected from different locations of the substrate to

different portions of the detection system **164**, the detection system **164** is capable of simultaneous multi-location multi-spectral measurements.

(58) FIG. **4**A is a cross-sectional view of the exit of an optical fiber bundle **310** configured to transmit and receive light in a processing chamber **100**, in accordance with one example of the disclosure. More specifically, FIG. **4**A illustrates the incident light beam **176**, as rays of incident light **236**, having been **236** transmitted by the plurality of optical fibers **302**. The rays of incident light **236** emitting from each fiber bundle exit **264** has an initial spot size **260** approximately equal to the optical fiber bundle **104** diameter. The initial spot size **260** of the plurality of fibers **302** is a reduction from the initial spot size **260** shown in FIG. **2**.

(59) FIG. **4**B is an example cross-sectional view of the light beams transmitted from the plurality of optical fibers **302**, as received, and reflected at the surface of substrate **120**, in accordance with one example of the disclosure. More specifically, FIG. **4**B is a cross-sectional view of rays of incident light **236** received from the plurality of optical fibers **302**, optical fiber **302***a*, optical fiber **302***b*, optical fiber **302***c*, and optical fiber **302***d*, and reflected as rays of reflected light **240**, from a plurality of reflection areas **302**′, a reflection area **302***a*′, a reflection area **302***a*′, a reflection area **302***a*′, and a reflection area **302***a*′, falling within, or about, the area of substrate image size **242** on substrate **120** shown in FIG. **4**. The rays of reflected light **240** emanating from the reflection areas **302**′ have a substrate image size **242**. The substrate image size **242** is larger than the initial spot size **260**. For example, the substrate image size **242** has a diameter between about 0.1 mm and 10 mm. The substrate image size **242** is about 0.05 mm to 4 mm. For example, the substrate image size **242** is about 1 mm. The substrate image size **242** shown in FIG. **4**B is a reduction from the substrate image size **242** shown in FIG. **2**B. Each reflection area of the plurality of reflection areas **302**′ returns a polychromatic reflected spectra of a different area of the substrate, simultaneously, for analysis and measurement by the detection system **164**.

(60) The optical fiber bundle **310** disclosed herein, by having a plurality of optical fibers **302**, enables an increase in the number of reflection areas **302**′. Each of the reflection areas **302**′ includes a reduced substrate image size **242** is a reduction from the substrate image size **242** of the example of FIG. **2**. In one example, which may be combined with other examples, reducing the input fiber diameter allows having a reduced substrate image size **242** allows about a ten-times, or more, improvement in spatial resolution when compared to current reflectometry devices and methods.

(61) In another example, which may be combined with other examples, the optical fiber bundle **310** disclosed herein, by having a plurality of optical fibers **302**, improves reflectometer sensitivity by permitting the entire spectra for each fiber measuring a smaller and separate area of the substrate. In another example, which may be combined with other examples, the increase in the number of reflection areas **302**′, each having a reduced substrate image size **242**, may allow for more areas of a substrate to be analyzed separately at the same time, and with increased sensitivity, when compared to current reflectometry devices and methods. In another example, which may be combined with other examples, the increase in the number of reflection areas **302**′ having a reduced substrate image size **242** may allow for differential measurement improving detection sensitivity. For example, the reflection area **302***a*′ may fall upon a portion of the substrate without features, with less features, or more features, than reflection area **302***d*′ allowing for differential measurement between the two areas of the substrate. In another example, which may be combined with other examples, the increase in the number of reflection areas **302**′ having a reduced substrate image size **242** may allow for each portion of the reflected light beam **178** collected by the plurality of optical fibers **302** to each go into a different portion of the detection system **164** for analysis.

(62) FIG. **5**A shows a graph **500**, titled “Single Wavelength Referencing” illustrates the drift in intensity of an example light source, for example light source **166**, over time, and how a detection system, such as detection system **164**, compensates for intensity drift by referencing improving signal stability and SNR.

(63) Graph **500** includes two axes. A horizontal axis **510**, labeled “TIME”, illustrates an increases in time from the left side of the graph, t0, to the right side of the graph, t+n. A vertical axis **520**, labeled “INTENSITY”, illustrates an intensity value showing increase in intensity above about point **522**, and a decrease in intensity below about point **522**.

(64) Graph **500** includes two plotted trend lines, a first trend line **502**, and a second trend line **504**. The first trend line **502** illustrates the drift in intensity of an example light source, for example light source **166**, over time. Looking at the first trend line **502**, it is illustrated that initially, the intensity of the light source first begins a sharp increase in intensity **502***a*, followed by sharp decrease in intensity **502***b*. Shortly after, the intensity decrease begins to taper, **502***c*, and arrive at semi-continuous intensity **502***d*.

(65) This change in intensity over time presents a problem for a detection system. Without referencing, such as illustrated by the first trend line **502**, a measurement taken at a point in time, could not be reliably compared to a measurement taken at a later point in time as the change intensity innately changes the measured value.

(66) The second trend line **504** illustrates the drift in intensity of an example light source, for example light source **166**, over time with referencing by the detection system **164**. Using referencing, the sharp increase and decrease of the first trend line **502** is instead a damped rise **504***a* followed by a constant intensity value **504***b*. Using referencing, the intensity of the light source is normalized, and the SNR is improved.

(67) FIG. **5**B shows a graph **550**, titled “Multiple Wavelength Referencing” illustrates the improvement in SNR gained by referencing in the detection system **164** over multiple wavelengths of light. Graph **550** includes two axes. A horizontal axis **510**, labeled “INTENSITY”, illustrates a variety of light source intensities at different wavelengths from the left side of the graph **550** to the right side of graph **550**. A vertical axis **520**, labeled “SNR”, plots the improvement in signal-to-noise.

(68) Graph **550** includes two plotted areas, a first area **552** without referencing, and a second area **554** with referencing. The first area **552** illustrates that without referencing, as lamp intensity increases, there is a small improvement in SNR across multiple wavelengths of light. The second area **554** illustrates, that with referencing, the detection system **164** as described herein can improve the SNR over the multiple wavelengths of light.

(69) FIG. **6** is a flow diagram of a method **600** for emitting and collecting reflected light within a processing chamber, in accordance with one example of the disclosure. Method **600** may be understood with reference to FIGS. **4**, and **4**A-**4**B. FIG. **6** includes a simplified version of the claimed subject matter and is not intended to constrain the present disclosure.

(70) Operation **610** of method **600** includes transmitting a first portion of an incident light beam to at least one area of a substrate **120** disposed within a processing chamber **100**.

(71) Operation **610** of method **600** may include transmitting, via an optical fiber bundle **310** comprising at least a first optical fiber, an incident light beam **176** from a light source **166** to an optical splitter **172**. Operation **610** of method **600** may include transmitting at least a sub-portion of the incident light beam **176** from at least a first sub-area of the light source **166** to the at least a first optical fiber, receiving the at least a sub-portion of the incident light beam **176** at the optical splitter **172** from the at least a first optical fiber.

(72) Operation **610** of method **600** may include transmitting a first portion of the incident light beam **176**, via the optical fiber bundle **310**, from the optical splitter **172** to a lens assembly **168**. Operation **610** of method **600** may include dividing at least a sub-portion of the incident light beam **176** into at least a first sub-portion of incident light, wherein the at least a first sub-portion of incident light corresponds to the at least a first sub-area of the light source **166**, and returning the at least a first sub-portion of incident light from the optical splitter **172** to the at least a first optical fiber, and transmitting the at least a first sub-portion of incident light from the at least a first optical fiber to the lens assembly **168**.

(73) Operation **610** of method **600** may include focusing the first portion of the incident light beam **176** as rays of incident light from the lens assembly **168** upon at least one area of a substrate **120** disposed within a processing chamber **100**. Operation **610** of method **600** may include receiving, via the optical fiber bundle **310**, at least a first sub-portion of the incident light beam **176** from the optical splitter **172**, and focusing the at least a first sub-portion of the incident light beam **176** as rays of incident light **236** from the lens assembly **168** to at least at least one area of the substrate **120**.
(74) Operation **620** of method **600** includes transmitting a second portion of the incident light beam **176** as a reference light beam **206** to a detection system **164**.
(75) Operation **620** of method **600** may include transmitting a second portion of the incident light beam **176** as a reference light beam **206**, via a return fiber bundle **312** comprising at least one return fiber, from the optical splitter **172** to a detection system **164**.
(76) Operation **620** of method **600** may include dividing at least a sub-portion of the incident light beam **176** into at least a second sub-portion of incident light wherein the at least a second sub-portion of incident light corresponds to the at least a first sub-area of the light source **166**, transmitting the at least a second sub-portion of incident light from the optical splitter **172** to the at least a first return fiber as at least a first sub-portion of a reference light beam **206** to the detection system **164**, and receiving the at least a first sub-portion of a reference light beam **206** from the at least a first return fiber at the detection system **164**, wherein the at least a first sub-portion of a reference light beam **206** corresponds to the at least a first sub-area of the light source **166**.
(77) Operation **630** of method **600** includes receiving the first portion of the incident light beam **176** from the at least one area of the substrate **120** as a reflected light beam **178** at the detection system **164**.
(78) Operation **630** of method **600** may include receiving rays of reflected light **240** from the at least one area of the substrate **120** at the lens assembly **168**, transmitting the rays of reflected light **240**, as at least a first sub-portion of a reflected light beam **178**, from the lens assembly **168** to at least a first optical fiber of the optical fiber bundle **310**, transmitting the rays of reflected light **240** as a reflected light beam **178** from the lens assembly **168**, via the optical fiber bundle **310**, to the optical splitter **172**, and transmitting the reflected light beam **178** from the optical splitter **172**, via the return fiber bundle **312**, to the detection system **164**.
(79) Operation **630** of method **600** may include receiving, from at least one area of the substrate **120**, rays of reflected light **240** at the lens assembly **168**, and transmitting the rays of reflected light **240**, as at least a first sub-portion of a reflected light beam **178**, from the lens assembly **168** to at least a first optical fiber.
(80) Operation **640** of method **600** includes determining at least on characteristic of the area of the substrate **120**.
(81) Operation **640** of method **600** may include receiving at least a first sub-portion of a reference light beam **206**, wherein the at least a first sub-portion of a reference light beam **206** corresponds to the at least a first sub-area of the light source **166**, receiving at least a first sub-portion of a reflected light beam **178**, wherein at least the first sub-portion of the reflected light beam **178**, corresponds to at least a first sub-portion of incident light, wherein the at least a first sub-portion of incident light corresponds to the at least the first sub-area of the light source **166**, and referencing the first sub-portion of the reference light beam **206** to the first sub-portion of a reflected light beam **178** to improve a first signal-to-noise ratio (SNR).
(82) Operation **640** of method **600** may include analyzing a full spectrum of the reflected light beam **178** based, in part, on the first SNR, wherein the full spectrum is between about 200 nanometers (nm) to about 800 nm.
(83) Operation **640** of method **600** may include determining, based upon the first SNR, and analyzing full spectrum of the reflected light beam **178**: at least one height of a feature disposed on the at least one area substrate **120**, at least one dimension of a feature disposed on the at least one

area substrate **120**, at least one wavelength of a radiant emission of a plasma from the at least one area of the substrate **120**, at least one intensity of the radiant emission of the plasma from the at least one area of the substrate **120**, or a combination thereof.

(84) Operation **640** of method **600** may include receiving at least a first sub-portion of a reference light beam **206**, wherein the at least a first sub-portion of a reference light beam **206** corresponds to at least a first sub-area of the light source **166**, receiving at least a second sub-portion of a reference light beam **206**, wherein the at least a second sub-portion of a reference light beam **206** corresponds to at least a second sub-area of the light source **166**, receiving at least a first sub-portion of a reflected light beam **178** from at least a first area of the substrate **120**, wherein at least the first sub-portion of the reflected light beam **178**, corresponds to at least a first sub-portion of incident light, wherein the at least a first sub-portion of incident light corresponds to the at least the first sub-area of the light source **166**, receiving at least a second sub-portion of a reflected light beam **178** from at least a second area of the substrate **120**, wherein at least the second sub-portion of the reflected light beam **178**, corresponds to at least a second sub-portion of incident light, wherein the at least a second sub-portion of incident light corresponds to the at least the second sub-area of the light source **166**, referencing the first sub-portion of the reference light beam **206** to the first sub-portion of a reflected light beam **178** to improve a first SNR, and referencing the second sub-portion of the reference light beam **206** to the second sub-portion of a reflected light beam **178** to improve a second SNR.

(85) Operation **640** of method **600** may include analyzing a full spectrum of at least the first sub-portion of a reflected light beam **178** based, in part, on the first SNR, wherein the full spectrum is between about 200 nanometers (nm) to about 800 nm, and analyzing a full spectrum of at least the second sub-portion of a reflected light beam **178** based, in part, on the second SNR, wherein the full spectrum is between about 200 nanometers (nm) to about 800 nm.

(86) Operation **640** of method **600** may include determining at least one characteristic at least a first area of the substrate **120** based upon the improved first SNR, and analyzing a full spectrum of at least the first sub-portion of a reflected light beam **178**, wherein determining the at least one characteristic further comprises determining: at least one height of a feature disposed on at least the first area of the substrate **120**, at least one dimension of a feature disposed on at least the first area of the substrate **120**, at least one wavelength of a radiant emission of a plasma from at least the first area of the substrate **120**, at least one intensity of the radiant emission of the plasma from at least the first area of the substrate **120**, or a combination thereof, determining at least one characteristic at least a second area of the substrate **120** based upon the improved first SNR, and analyzing a full spectrum of at least the second sub-portion of a reflected light beam **178**, wherein determining the at least one characteristic further comprises determining: at least one height of a feature disposed on at least the second area of the substrate **120**, at least one dimension of a feature disposed on at least the second area of the substrate **120**, at least one wavelength of a radiant emission of a plasma from at least the second area of the substrate **120**, at least one intensity of the radiant emission of the plasma from at least the second area of the substrate **120**, or a combination thereof, and comparing the at least one characteristic of at least the first area of the substrate **120** to the at least one characteristic of at least the second area of the substrate **120** to improve detection density of the at least one characteristic of at least the second area of the substrate **120**.

(87) Operation **560** of method **600** includes repeating prior operations, operation **610**, operation **620**, operation **630**, and/or operation **640** as needed, until measurement and analysis of the substrate **120** is complete.

Additional Considerations

(88) While this specification contains many specific implementation details, these should not be construed as limitations on the scope of what may be claimed, but rather as descriptions of features that may be specific to particular implementations. Certain features that are described in this specification in the context of separate implementations may also be implemented, in combination,

in a single implementation. Conversely, various features that are described in the context of a single implementation may also be implemented in multiple implementations, separately, or in any suitable sub-combination. Moreover, although previously described features may be described as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination may, in some cases, be excised from the combination, and the claimed combination may be directed to a sub-combination or variation of a sub-combination.

(89) Particular implementations of the subject matter have been described. Other implementations, alterations, and permutations of the described implementations are within the scope of the following claims as will be apparent to those skilled in the art. While operations are depicted in the drawings or claims in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed (some operations may be considered optional) to achieve desirable results. In certain circumstances, multitasking or parallel processing (or a combination of multitasking and parallel processing) may be advantageous and performed as deemed appropriate.

(90) Moreover, the separation or integration of various system modules and components in the previously described implementations should not be understood as requiring such separation or integration in all implementations. It should be understood that the described program components and systems may generally be integrated together in a single software product or packaged into multiple software products.

(91) Accordingly, the previously described example implementations do not define or constrain the present disclosure. Other changes, substitutions, and alterations are also possible without departing from the spirit and scope of the present disclosure.

(92) While the various steps in an embodiment method or process are presented and described sequentially, one of ordinary skill in the art will appreciate that some or all of the steps may be executed in different order, may be combined or omitted, and some or all of the steps may be executed in parallel. The steps may be performed actively or passively. The method or process may be repeated or expanded to support multiple components or multiple users within a field environment. Accordingly, the scope should not be considered limited to the specific arrangement of steps shown in a flowchart or diagram.

(93) Unless defined otherwise, all technical and scientific terms used have the same meaning as commonly understood by one of ordinary skill in the art to which these systems, apparatuses, methods, processes and compositions belong.

(94) In this disclosure, the terms “top”, “bottom”, “side”, “above”, “below”, “up”, “down”, “upward”, “downward”, “horizontal”, “vertical”, and the like do not refer to absolute directions. Instead, these terms refer to directions relative to a nonspecific plane of reference. This non-specific plane of reference may be vertical, horizontal, or other angular orientation.

(95) The singular forms “a,” “an,” and “the” include plural referents, unless the context clearly dictates otherwise. Within a claim, reference to an element in the singular is not intended to mean “one and only one” unless specifically so stated, but rather “one or more.” Unless specifically stated otherwise, the term “some” refers to one or more.

(96) Embodiments of the present disclosure may suitably “comprise”, “consist” or “consist essentially of” the limiting features disclosed, and may be practiced in the absence of a limiting feature not disclosed. As used here and in the appended claims, the words “comprise,” “has,” and “include” and all grammatical variations thereof are each intended to have an open, non-limiting meaning that does not exclude additional elements or steps.

(97) “Optional” and “optionally” means that the subsequently described material, event, or circumstance may or may not be present or occur. The description includes instances where the material, event, or circumstance occurs and instances where it does not occur.

(98) As used, the term “determining” encompasses a wide variety of actions. For example, “determining” may include calculating, computing, processing, deriving, investigating, looking up,

for example, looking up in a table, a database or another data structure, and ascertaining. Also, “determining” may include receiving, for example, receiving information, and accessing, for example, accessing data in a memory. Also, “determining” may include resolving, selecting, choosing, and establishing.
(99) When the word “approximately” or “about” are used, this term may mean that there may be a variance in value of up to ±10%, of up to 5%, of up to 2%, of up to 1%, of up to 0.5%, of up to 0.1%, or up to 0.1%.
(100) Ranges may be expressed as from about one particular value to about another particular value, inclusive. When such a range is expressed, it is to be understood that another embodiment is from the one particular value to the other particular value, along with all particular values and combinations thereof within the range.
(101) As used, terms such as “first” and “second” are arbitrarily assigned and are merely intended to differentiate between two or more components of a system, an apparatus, or a composition. It is to be understood that the words “first” and “second” serve no other purpose and are not part of the name or description of the component, nor do they necessarily define a relative location or position of the component. Furthermore, it is to be understood that that the mere use of the term “first” and “second” does not require that there be any “third” component, although that possibility is envisioned under the scope of the various embodiments described.
(102) As used, “a CPU,” “a processor,” “at least one processor” or “one or more processors” generally refers to a single processor configured to perform one or multiple operations or multiple processors configured to collectively perform one or more operations. In the case of multiple processors, performance the one or more operations could be divided amongst different processors, though one processor may perform multiple operations, and multiple processors could collectively perform a single operation. Similarly, “a memory,” “at least one memory” or “one or more memories” generally refers to a single memory configured to store data and/or instructions, multiple memories configured to collectively store data and/or instructions.
(103) Although only a few example embodiments have been described in detail, those skilled in the art will readily appreciate that many modifications are possible in the example embodiments without materially departing from the disclosed scope as described. Accordingly, all such modifications are intended to be included within the scope of this disclosure as defined in the following claims.

## Claims

1. An optical reflectometry system, comprising: a processing chamber having a ceiling, sidewalls, and a bottom defining an internal volume, wherein the ceiling contains a transparent window; a substrate support located in the internal volume, wherein the substrate support is configured to accept a substrate; a light source located outside of the internal volume configured to transmit an incident light beam; an optical fiber bundle located outside of the internal volume comprising at least a first optical fiber coupled to the light source and optically coupled to a lens assembly, wherein the lens assembly is disposed above the transparent window, and optically coupled to at least the first optical fiber, and configured to: transmit the incident light beam, as rays of incident light, to at least one area of the substrate, through the transparent window, receive rays of reflected light, from the at least one area of the substrate, through the transparent window, and transmit the rays of reflected light, as a reflected light beam, to the optical fiber bundle; an optical splitter disposed within the optical fiber bundle; and a return fiber bundle comprising at least a first return fiber coupled to the optical splitter and coupled to a detection system, wherein the detection system is configured to: reference a reference light beam and the reflected light beam to improve a signal-to-noise ratio (SNR), analyze a full spectrum of the reflected light beam based, in part, on the SNR, and determine at least one characteristic of the at least one area of the substrate based upon the

analysis.
2. The optical reflectometry system of claim 1, wherein the full spectrum is between about 200 nanometers (nm) to about 800 nm.
3. The optical reflectometry system of claim 1, wherein the at least one characteristic of the at least one area of the substrate comprises: at least one height of a feature disposed the at least one area of the substrate; at least one dimension of a feature disposed on the at least one area of the substrate; at least one wavelength of a radiant emission of a plasma from the at least one area of the substrate; at least one intensity of the radiant emission of the plasma from the at least one area of the substrate; or a combination thereof.
4. The optical reflectometry system of claim 1, wherein the light source is a monochromatic light source.
5. The optical reflectometry system of claim 1, wherein the light source is a polychromatic light source.
6. The optical reflectometry system of claim 1, wherein the at least the first optical fiber is configured to: receive a at least a sub-portion of the incident light beam from at least a first sub-area of the light source; transmit at least the sub-portion of the incident light beam; receive at least the sub-portion of the reflected light beam; and transmit at least the sub-portion of the reflected light beam.
7. The optical reflectometry system of claim 1, wherein the at least the first optical fiber has a diameter between about 0.1 millimeters (mm) and about 0.5 mm.
8. The optical reflectometry system of claim 1, wherein an area, of the at least one area of the substrate, has a substrate image size with a diameter between about 0.1 millimeters (mm) and about 10 mm.
9. The optical reflectometry system of claim 1, wherein at least the first return fiber is configured to: receive at least a sub-portion of the reference light beam; transmit at least the sub-portion of the reference light beam; receive at least a first sub-portion of the reflected light beam; and transmit at least the sub-portion of the reflected light beam.
10. The optical reflectometry system of claim 1, wherein the optical splitter is configured to: receive a at least a sub-portion of the incident light beam from the at least the first optical fiber; divide at least the sub-portion of the incident light beam into at least a first sub-portion of incident light of and at least a second sub-portion of incident light; transmit the at least the first sub-portion of incident light to at least the first optical fiber; transmit at least the second sub-portion of incident light to at least the first return fiber as at least a sub-portion of the reference light beam, receive at least the sub-portion of the reflected light beam; and transmit at least the sub-portion of the reflected light beam to at least a second return fiber.
11. The optical reflectometry system of claim 1, wherein the lens assembly comprises at least one focusing lens, and the lens assembly is configured to: receive at least a first sub-portion of incident light from the at least the first optical fiber; focus the at least a first sub-portion of incident light to at least one area of the substrate; receive rays of reflected light from at least one area of the substrate; and transmit rays of reflected light as at least a first sub-portion of the reflected light beam to the at least the first optical fiber.
12. The optical reflectometry system of claim 11, wherein the at least a first area of the substrate has substrate image size diameter between about 0.1 mm and 10 mm.
13. The optical reflectometry system of claim 1, wherein the detection system comprises a spectroscopic reflectometry system is further configured to: receive at least a sub-portion of the reference light beam, wherein at least the sub-portion of the reference light beam corresponds to at least a first sub-area of the light source; and receive at least a sub-portion of the reflected light beam, wherein at least the sub-portion of the reflected light beam corresponds to at least the first sub-area of the light source.
14. A method of optical reflectometry, comprising: transmitting, via an optical fiber bundle

comprising at least a first optical fiber, an incident light beam from a light source to an optical splitter; transmitting a first portion of the incident light beam, via the optical fiber bundle, from the optical splitter to a lens assembly; transmitting a second portion of the incident light beam as a reference light beam, via a return fiber bundle comprising at least one return fiber, from the optical splitter to a detection system; focusing the first portion of the incident light beam as rays of incident light from the lens assembly upon at least one area of a substrate disposed within a processing chamber; receiving rays of reflected light from the at least one area of the substrate at the lens assembly; transmitting the rays of reflected light as a reflected light beam from the lens assembly, via the optical fiber bundle, to the optical splitter; transmitting the reflected light beam from the optical splitter, via the return fiber bundle, to the detection system; referencing the reference light beam to the reflected light beam to improve a signal-to-noise ratio (SNR); analyzing a full spectrum of the reflected light beam based, in part, on the improved SNR; and determining at least one characteristic of the at least one area of the substrate upon the analysis.

15. The method of claim 14, wherein transmitting the incident light beam from the light source to the optical splitter further comprises: transmitting at least a sub-portion of the incident light beam from at least a first sub-area of the light source to the at least the first optical fiber; and receiving the at least a sub-portion of the incident light beam at the optical splitter from the at least the first optical fiber.

16. The method of claim 14, wherein transmitting the first portion of the incident light beam from the optical splitter to the lens assembly further comprises: dividing at least a sub-portion of the incident light beam into at least a first sub-portion of incident light, wherein the at least a first sub-portion of incident light corresponds to the at least a first sub-area of the light source; and returning the at least the first sub-portion of incident light from the optical splitter to the at least the first optical fiber; and transmitting the at least a first sub-portion of incident light from the at least the first optical fiber to the lens assembly.

17. The method of claim 14, wherein transmitting the second portion of the incident light beam as the reference light beam from the optical splitter to the detection system further comprises: dividing at least a sub-portion of the incident light beam into at least a second sub-portion of incident light wherein the at least a second sub-portion of incident light corresponds to the at least a first sub-area of the light source; transmitting the at least a second sub-portion of incident light from the optical splitter to the at least a first return fiber as at least a first sub-portion of the reference light beam; and receiving the at least a first sub-portion of the reference light beam from at least the first return fiber at the detection system, wherein the at least a first sub-portion of the reference light beam corresponds to the at least a first sub-area of the light source.

18. The method of claim 14, wherein focusing the first portion of the incident light beam as rays of incident light from the lens assembly upon at least one area of a substrate disposed within a processing chamber further comprises: receiving, via the optical fiber bundle, at least a first sub-portion of the incident light beam from the optical splitter; and focusing the at least a first sub-portion of the incident light beam as rays of incident light from the lens assembly to at least at least one area of the substrate.

19. The method of claim 14, wherein transmitting the rays of reflected light as the reflected light beam from the lens assembly, via the optical fiber bundle, to the optical splitter further comprises: receiving, from at least one area of the substrate, rays of reflected light at the lens assembly; and transmitting the rays of reflected light, as at least a first sub-portion of the reflected light beam, from the lens assembly to at least the first optical fiber.

20. The method of claim 14, wherein referencing the reference light beam to the reflected light beam to improve the signal-to-noise ratio further comprises: receiving at least a first sub-portion of the reference light beam, wherein the at least a first sub-portion of the reference light beam corresponds to the at least a first sub-area of the light source; receiving at least a first sub-portion of the reflected light beam, wherein at least the first sub-portion of the reflected light beam,

corresponds to at least a first sub-portion of incident light, wherein the at least a first sub-portion of incident light corresponds to the at least the first sub-area of the light source; and referencing the first sub-portion of the reference light beam to the first sub-portion of the reflected light beam to improve a first signal-to-noise ratio (SNR).

21. The method of claim 14, wherein analyzing a full spectrum of the reflected light beam based, in part, on the improved SNR, further comprises: analyzing a full spectrum of at least a first sub-portion of the reflected light beam based, in part, on a first signal-to-noise ratio (SNR), wherein the full spectrum is between about 200 nanometers (nm) to about 800 nm.

22. The method of claim 14, wherein determining at least one characteristic of the at least one area of the substrate further comprises: determining, based upon a first signal-to-noise ratio (SNR) and analyzing a full spectrum of the reflected light beam: at least one height of a feature disposed on the at least one area of the substrate; at least one dimension of a feature disposed the at least one area of the substrate; at least one wavelength of a radiant emission of a plasma from the at least one area of the substrate; at least one intensity of the radiant emission of the plasma from the at least one area of the substrate; or a combination thereof.

23. The method of claim 14, wherein referencing the reference light beam to the reflected light beam to improve the signal-to-noise ratio (SNR) further comprises: receiving at least a first sub-portion of the reference light beam, wherein the at least a first sub-portion of a reference light beam corresponds to at least a first sub-area of the light source; receiving at least a second sub-portion of the reference light beam, wherein the at least a second sub-portion of the reference light beam corresponds to at least a second sub-area of the light source; receiving at least a first sub-portion of the reflected light beam from at least a first area of the substrate, wherein at least the first sub-portion of the reflected light beam, corresponds to at least a first sub-portion of incident light, wherein the at least a first sub-portion of incident light corresponds to the at least the first sub-area of the light source; receiving at least a second sub-portion of the reflected light beam from at least a second area of the substrate, wherein at least the second sub-portion of the reflected light beam, corresponds to at least a second sub-portion of incident light, wherein the at least a second sub-portion of incident light corresponds to the at least the second sub-area of the light source; referencing the first sub-portion of the reference light beam to the first sub-portion of the reflected light beam to improve a first SNR; and referencing the second sub-portion of the reference light beam to the second sub-portion of the reflected light beam to improve a second SNR.

24. The method of claim 14, wherein analyzing a full spectrum of the reflected light beam based, in part, on the improved SNR, further comprises: analyzing a full spectrum of at least a first sub-portion of the reflected light beam based, in part, on a first signal-to-noise ratio (SNR), wherein the full spectrum is between about 200 nanometers (nm) to about 800 nm; and analyzing a full spectrum of at least a second sub-portion of the reflected light beam based, in part, on a second SNR, wherein the full spectrum is between about 200 nanometers (nm) to about 800 nm.

25. The method of claim 14, wherein determining at least one characteristic of the at least one area of the substrate based upon the analysis further comprises: determining at least one characteristic at least a first area of the substrate based upon an improved first SNR, and analyzing a full spectrum of at least a first sub-portion of the reflected light beam, wherein determining the at least one characteristic further comprises determining: at least one height of a feature disposed on at least the first area of the substrate; at least one dimension of a feature disposed on at least the first area of the substrate; at least one wavelength of a radiant emission of a plasma from at least the first area of the substrate; at least one intensity of the radiant emission of the plasma from at least the first area of the substrate; or a combination thereof; determining at least one characteristic at least a second area of the substrate based upon an improved second SNR, and analyzing a full spectrum of at least a second sub-portion of the reflected light beam, wherein determining the at least one characteristic further comprises determining: at least one height of a feature disposed on at least the second area of the substrate; at least one dimension of a feature disposed on at least the second area

of the substrate; at least one wavelength of a radiant emission of a plasma from at least the second area of the substrate; at least one intensity of the radiant emission of the plasma from at least the second area of the substrate; or a combination thereof; and comparing the at least one characteristic of at least the first area of the substrate to the at least one characteristic of at least the second area of the substrate to improve detection density of the at least one characteristic of at least the second area of the substrate.