methods such as endpoint detection (EPD), in which precise timing of the process endpoint is of paramount importance.

[0008] With present demands of process diagnostics, particularly etch diagnostics, the aforementioned tradeoffs are becoming more severe with every new generation of devices and processes. Therefore, the need exists for a new spectrometer design and optical diagnostic system to be used in in-situ semiconductor processing diagnostics and control, which does not require sacrificing throughput and spectral resolution for increasing signal to noise ratio (SNR), or which minimizes these tradeoffs.

[0009] To that end, this invention proposes a system and method for optical diagnostics and control of a semiconductor manufacturing process using hyperspectral imaging technology as replacement for a conventional spectrometer.

[0010] Because hyperspectral imaging is an imaging technique, it is applicable to an even wider range of optical diagnostic methods in semiconductor processing. For example, optical diagnostics that involve imaging of the substrate or region(s) of the substrate to determine the state of the substrate and structures and layers formed thereupon, where the diagnostics would benefit from the knowledge of full spectral information afforded by hyperspectral imaging, are all good candidates for the use of this technology. Examples of optical diagnostics where hyperspectral imaging can be employed include various optical imaging inspection steps, such as after-develop inspection (ADI) in photolithographic patterning processes, various imaging defect inspection steps, detection of contamination on the substrate, etc.

SUMMARY OF THE INVENTION

[0011] The present invention relates to methods, and multiple embodiments of an apparatus and system for hyperspectral imaging, to diagnose the state of a substrate during semiconductor processing, and/or to optically diagnose and control the state of a semiconductor manufacturing process itself.

[0011a] According to a first aspect of the present invention, there is provided an optical detector for detecting an optical signal from a semiconductor processing system, the optical detector being configured for detecting an optical signal transmitted through a window mounted in a wall of the semiconductor processing system, the optical detector comprising:

collecting optics, configured for collecting and transmitting the optical signal transmitted by the window;

a ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity for tunably selecting a wavelength of the transmitted optical signal;

an array detector for detecting the wavelength-filtered optical signal; and

a controller for controlling at least the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity and array detector, and for storing and processing images acquired by the array detector.

~~[0011b] According to a second aspect of the present invention, there is provided an optical detector for detecting an optical signal reflected from a substrate in a semiconductor substrate inspection system, the optical detector comprising:~~

~~collecting optics, configured for collecting and transmitting the optical signal;~~

~~a wavelength tunable filter for tunably selecting a wavelength of the transmitted optical signal;~~

~~an array detector for detecting the wavelength-filtered optical signal; and~~

~~a controller for controlling at least the wavelength tunable filter and array detector, and for storing and processing images acquired by the array detector.~~

[0011~~c~~b] According to a ~~third~~ second aspect of the present invention, there is provided a semiconductor processing system, comprising:

a window mounted in a wall of the semiconductor processing system;

collecting optics, configured for collecting and transmitting an optical signal transmitted by the window from the semiconductor processing system;

a ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity for tunably selecting a wavelength of the transmitted optical signal;

an array detector for detecting the wavelength-filtered optical signal; and

a controller for controlling at least the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity and array detector, and for storing and processing images acquired by the array detector.

[0011c] According to a third aspect of the present invention, there is provided a substrate inspection system comprising:

a stage for receiving a substrate to be inspected;

an illumination light source, for illuminating the substrate;

collecting optics, configured for collecting and transmitting an optical signal caused by illuminating the substrate;

a tunable Fabry Perot cavity for tunably selecting a wavelength of the transmitted optical signal;

an array detector for detecting the wavelength-filtered optical signal; and

a controller for controlling at least the tunable Fabry Perot cavity and array detector, and for storing and processing images acquired by the array detector.

[0011d] According to a fourth aspect of the present invention, there is provided a method for diagnosing a plasma process step in a plasma processing system, comprising:

igniting a plasma in a plasma processing chamber of the plasma processing system;

collecting a plasma optical emission signal through a window mounted in a wall of the plasma processing chamber, and through collecting optics;

directing the plasma optical emission signal from the collecting optics into a ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity for tunably selecting a wavelength of the collected plasma optical emission signal;

detecting the wavelength-filtered plasma optical emission signal using an array detector; and

storing and processing images acquired by the array detector in a controller,

wherein the controller is configured for controlling at least the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity and the array detector.

[0011e] According to a fifth aspect of the present invention, there is provided a method for measuring at least one property of at least one layer or structure formed on a substrate disposed in a semiconductor processing system, comprising:

initiating a process step in the semiconductor processing system;

illuminating the substrate with an illumination beam, the portion of the illumination beam reflected and diffracted from the substrate forming a diffracted optical signal;

collecting the diffracted optical signal through a window mounted in a wall of the semiconductor processing system, and through collecting optics;

tunably selecting a wavelength of either the illumination beam or the diffracted optical signal using a ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity disposed in either the illumination beam or the diffracted optical signal, respectively, to form a wavelength-filtered diffracted optical signal;

detecting the wavelength-filtered diffracted optical signal using an array detector; and

storing and processing images acquired by the array detector in a controller,

wherein the controller is configured for controlling at least the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity and the array detector.

[0011f] According to a sixth aspect of the present invention, there is provided a method for inspecting a substrate in a substrate inspection system, comprising:

placing the substrate on a stage in the substrate inspection system;

illuminating the substrate with an illumination light source;

collecting an optical signal caused by illuminating the substrate, through collecting optics;

directing the collected optical signal from the collecting optics into a ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity for tunably selecting a wavelength of the collected optical signal;

detecting the wavelength-filtered signal using an array detector; and

storing and processing images acquired by the array detector in a controller,

wherein the controller is configured for controlling at least the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity and the array detector.

[0012] In one embodiment, an optical detector for detecting an optical signal from a semiconductor processing system is provided. The optical detector is configured for detecting an optical signal transmitted through a window mounted in a wall of the semiconductor processing system. The optical detector comprises collecting optics, configured for collecting and transmitting the optical signal transmitted by the window; a wavelength tunable filter for tunably selecting a wavelength of the transmitted optical

What is claimed is:

1. An optical detector for detecting an optical signal from a semiconductor processing system, the optical detector being configured for detecting an optical signal transmitted through a window mounted in a wall of the semiconductor processing system, the optical detector comprising:

collecting optics, configured for collecting and transmitting the optical signal transmitted by the window;

a ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity for tunably selecting a wavelength of the transmitted optical signal;

an array detector for detecting the wavelength-filtered optical signal; and

a controller for controlling at least the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity and array detector, and for storing and processing images acquired by the array detector.

2. The ~~apparatus~~ optical detector of claim 1, wherein the semiconductor processing system is a plasma processing system, and the optical signal comprises a plasma optical emission signal.

3. The ~~apparatus~~ optical detector of claim 1, wherein the optical signal comprises a diffracted optical signal, the diffracted optical signal being formed by reflecting and diffracting an illumination beam from a surface of the substrate disposed in the semiconductor processing system.

4. The ~~apparatus~~ optical detector of claim 3, wherein the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity is disposed in the illumination beam, for tunably selecting a wavelength of the illumination beam.

5. The ~~apparatus~~ optical detector of claim 3, wherein the illumination beam has an angle of incidence of 0 degrees upon the surface of the substrate, and the diffracted optical signal is acquired at an angle of reflection of 0 degrees.

6. The ~~apparatus~~ optical detector of claim 3, wherein the illumination beam has an angle of incidence upon the surface of the substrate from 0.1 degree to 89

degrees, and the diffracted optical signal is acquired at an angle of reflection from 0.1 degree to 89 degrees.

7. The ~~apparatus~~ optical detector of claim 1, wherein the collecting optics comprise a collecting lens, a steering mirror, an aperture, a polarizer, an optical fiber, or a combination of two of more thereof.

~~8. The apparatus of claim 1, wherein the wavelength tunable filter comprises a tunable Fabry Perot cavity, an acousto-optic tunable filter, a liquid crystal tunable filter, or a combination of two or more thereof.~~

~~9~~8. The ~~apparatus~~ optical detector of claim 1, wherein the array detector is one-dimensional or two-dimensional.

~~10~~9. The ~~apparatus~~ optical detector of claim 1, wherein the array detector comprises a CCD detector array, CMOS detector array, photodiode array, or a combination of two or more thereof.

~~11~~10. The ~~apparatus~~ optical detector of claim 1, wherein the controller is configured to selectively tune a passband wavelength of the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity, across a range or multiple overlapping or non-overlapping ranges of wavelengths in the deep ultraviolet (DUV), ultraviolet (UV), visible (VIS), and infrared (IR) portions of the optical spectrum.

~~12~~11. The ~~apparatus~~ optical detector of claim ~~11~~10, wherein the controller is configured to acquire an image cube, the image cube consisted of a set of images acquired by the array detector, each image in the set being acquired at a wavelength defined by an instantaneous passband wavelength to which the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity is tuned.

~~13. An optical detector for detecting an optical signal reflected from a substrate in a semiconductor substrate inspection system, the optical detector comprising:~~

~~collecting optics, configured for collecting and transmitting the optical signal;~~

~~a wavelength tunable filter for tunably selecting a wavelength of the transmitted optical signal;~~

~~an array detector for detecting the wavelength-filtered optical signal; and~~

~~a controller for controlling at least the wavelength tunable filter and array detector, and for storing and processing images acquired by the array detector.~~

~~14~~12. A semiconductor processing system, comprising:

a window mounted in a wall of the semiconductor processing system;

collecting optics, configured for collecting and transmitting an optical signal transmitted by the window from the semiconductor processing system;

a ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity for tunably selecting a wavelength of the transmitted optical signal;

an array detector for detecting the wavelength-filtered optical signal; and

a controller for controlling at least the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity and array detector, and for storing and processing images acquired by the array detector.

~~15~~13. The system of claim ~~14~~12, wherein the semiconductor processing system is a plasma processing system, and the optical signal comprises a plasma optical emission signal.

~~16~~14. The system of claim ~~14~~12, wherein the optical signal comprises a diffracted optical signal, the diffracted optical signal being formed by reflecting and diffracting an illumination beam from a surface of a substrate disposed in the semiconductor processing system.

~~17~~15. The system of claim ~~16~~14, wherein the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity is disposed in the illumination beam, for tunably selecting a wavelength of the illumination beam.

~~18~~16. A substrate inspection system comprising:

a stage for receiving a substrate to be inspected;

an illumination light source, for illuminating the substrate;

collecting optics, configured for collecting and transmitting an optical signal caused by illuminating the substrate;

a ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity for tunably selecting a wavelength of the transmitted optical signal;

an array detector for detecting the wavelength-filtered optical signal; and

a controller for controlling at least the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity and array detector, and for storing and processing images acquired by the array detector.

~~19~~17. A method for diagnosing a plasma process step in a plasma processing system, comprising:

igniting a plasma in a plasma processing chamber of the plasma processing system;

collecting a plasma optical emission signal through a window mounted in a wall of the plasma processing chamber, and through collecting optics;

directing the plasma optical emission signal from the collecting optics into a ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity for tunably selecting a wavelength of the collected plasma optical emission signal;

detecting the wavelength-filtered plasma optical emission signal using an array detector; and

storing and processing images acquired by the array detector in a controller,

wherein the controller is configured for controlling at least the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity and the array detector.

~~20~~18. The method of claim 1~~9~~7, further comprising:

selectively tuning a passband wavelength of the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity, across a range or multiple overlapping or non-overlapping ranges of wavelengths in the deep ultraviolet (DUV), ultraviolet (UV), visible (VIS), and infrared (IR) portions of the optical spectrum.

~~21~~19. The method of claim ~~20~~18, further comprising:

forming an image cube, the image cube consisted of a set of images detected by the array detector, each image in the set being acquired at a wavelength defined by an

instantaneous passband wavelength to which the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity is tuned.

~~22~~20. The method of claim ~~21~~19, further comprising:

determining an endpoint of the plasma process step from a sequence of plasma optical emission spectra formed from a sequence of image cubes acquired during the plasma process step.

~~23~~21. The method of claim ~~21~~19, further comprising:

determining a relative concentration of at least one chemical constituent of the plasma from at least one plasma optical emission spectrum formed from at least one image cube.

~~24~~22. A method for measuring at least one property of at least one layer or structure formed on a substrate disposed in a semiconductor processing system, comprising:

initiating a process step in the semiconductor processing system;

illuminating the substrate with an illumination beam, the portion of the illumination beam reflected and diffracted from the substrate forming a diffracted optical signal;

collecting the diffracted optical signal through a window mounted in a wall of the semiconductor processing system, and through collecting optics;

tunably selecting a wavelength of either the illumination beam or the diffracted optical signal using a ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity disposed in either the illumination beam or the diffracted optical signal, respectively, to form a wavelength-filtered diffracted optical signal;

detecting the wavelength-filtered diffracted optical signal using an array detector; and

storing and processing images acquired by the array detector in a controller,

wherein the controller is configured for controlling at least the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity and the array detector.

~~25~~23. The method of claim ~~24~~22, further comprising:

selectively tuning a passband wavelength of the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity, across a range or multiple overlapping or non-overlapping ranges of wavelengths in the deep ultraviolet (DUV), ultraviolet (UV), visible (VIS), and infrared (IR) portions of the optical spectrum.

~~26~~24. The method of claim ~~25~~23, further comprising:

forming an image cube, the image cube consisted of a set of images detected by the array detector, each image in the set being acquired at a wavelength defined by an instantaneous passband wavelength to which the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity is tuned.

~~27~~25. The method of claim ~~26~~24, further comprising:

determining at least one property of a layer or structure formed on the substrate from at least one diffracted optical spectrum derived from at least one image cube.

~~28~~26. The method of claim ~~27~~25, wherein the at least one property of a layer or structure on the substrate is a profile top critical dimension (CD), a profile bottom critical dimension (CD), a profile middle critical dimension (CD), a profile sidewall angle, a layer thickness, a layer optical property, or a remaining thickness of a layer being etched.

~~29~~27. The method of claim ~~26~~24, further comprising:

determining an endpoint of the process step from a sequence of diffracted optical spectra derived from a sequence of image cubes acquired during the process step.

~~30~~28. The method of claim ~~26~~24, further comprising:

determining a spatial correspondence of locations on the substrate and pixel locations in images of at least one selected image cube; and

deriving at least one diffracted optical spectrum from the at least one selected image cube.

~~31~~29. The method of claim ~~30~~28, wherein the at least one diffracted optical spectrum is derived from a single selected pixel location across all images or a selected subset of images in the at least one selected image cube.

~~32~~30. The method of claim ~~30~~28, wherein the at least one diffracted optical spectrum is derived from at least one selected region of pixel locations across all images or a selected subset of images in the at least one selected image cube.

~~33~~31. The method of claim ~~30~~28, wherein the at least one diffracted optical spectrum is derived from all pixel locations across all images or a selected subset of images in the at least one selected image cube.

~~34~~32. The method of claim ~~26~~24, wherein at least two diffracted optical spectra are derived from a single pixel location across all images or a selected subset of images in at least two image cubes, and wherein the single pixel location is selected such that a rate of change of at least one light intensity between two derived diffracted optical spectra exceeds a pre-selected threshold rate of change of light intensity.

~~35~~33. The method of claim ~~26~~24, wherein at least two diffracted optical spectra are derived from a region of pixel locations across all images or a selected subset of images in at least two image cubes, and wherein the region of pixel locations is selected such that a rate of change of at least one light intensity between two derived diffracted optical spectra exceeds a pre-selected threshold rate of change of light intensity.

~~36~~34. A method for inspecting a substrate in a substrate inspection system, comprising:

placing the substrate on a stage in the substrate inspection system;

illuminating the substrate with an illumination light source;

collecting an optical signal caused by illuminating the substrate, through collecting optics;

directing the collected optical signal from the collecting optics into a ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity for tunably selecting a wavelength of the collected optical signal;

detecting the wavelength-filtered signal using an array detector; and

storing and processing images acquired by the array detector in a controller,

wherein the controller is configured for controlling at least the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity and the array detector.

~~37~~35. The method of claim ~~36~~34, further comprising:

selectively tuning a passband wavelength of the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity, across a range or multiple overlapping or non-overlapping ranges of wavelengths in the deep ultraviolet (DUV), ultraviolet (UV), visible (VIS), and infrared (IR) portions of the optical spectrum.

~~38~~36. The method of claim ~~37~~35, further comprising:

forming an image cube, the image cube consisted of a set of images detected by the array detector, each image in the set being acquired at a wavelength defined by an instantaneous passband wavelength to which the ~~wavelength~~ tunable ~~filter~~ Fabry Perot cavity is tuned.

~~39~~37. The method of claim ~~38~~36, further comprising:

determining at least one property of the substrate, or of a layer or structure formed on the substrate from at least one optical spectrum derived from at least one image cube.

~~40~~38. The method of claim ~~38~~36, further comprising:

determining a spatial correspondence of locations on the substrate and pixel locations in images of at least one selected image cube; and

determining at least one optical spectrum from the at least one selected image cube.

~~41~~39. The method of claim ~~40~~38, wherein the at least one optical spectrum is derived from a single selected pixel location across all images or a selected subset of images in the at least one selected image cube.

~~42~~40. The method of claim ~~40~~38, wherein the at least one optical spectrum is derived from at least one selected region of pixel locations across all images or a selected subset of images in the at least one selected image cube.

~~43~~41. The method of claim ~~40~~38, wherein the at least one optical spectrum is derived from all pixel locations across all images or a selected subset of images in the at least one selected image cube.