

CLAIMS

What is claimed is:

1. A system comprising:

an illumination source configured to generate a first amount of illumination light directed to a measurement spot on a surface of a specimen;

a collection objective configured to collect a first amount of collected light from the measurement spot on the surface of the specimen in response to the first amount of illumination light, the first amount of collected light including dark field scattering light within a collection pupil of the collection objective;

one or more mask elements in a first configuration located at or near a pupil plane of the collection objective, a pupil plane conjugate to the pupil plane of the collection objective, or any combination thereof, the one or more mask elements in the first configuration block a first portion of the first amount of collected light and transmit a second portion of the first amount of collected light, the second portion of the first amount of collected light selected by the one or more mask elements in the first configuration from at least two spatially distinct locations in the collection pupil;

an imaging detector having a photosensitive surface located at or near a field plane conjugate to the surface of the specimen, the imaging detector configured to detect a first interference pattern formed by the second portion of the first amount of collected light at or near the field plane; and

a computing system configured to:

receive an output signal indicative of the first interference pattern; and

determine a first phase difference between the transmitted light selected by the one or more mask elements in the first configuration from a first location of the at least two spatially distinct locations and the transmitted light selected by the one or more mask elements in the first configuration from a second location of the at least two spatially distinct locations from the first interference pattern.

2. The system of Claim 1, further comprising:

one or more mask elements in a second configuration located at or near the pupil plane of the collection objective, the pupil plane conjugate to the pupil plane of the collection objective, or any combination thereof,

wherein the illumination source is further configured to generate a second amount of illumination light directed to the measurement spot on the surface of the specimen,

wherein the collection objective is further configured to collect a second amount of collected light from the measurement spot on the surface of the specimen in response to the second amount of illumination light, the second amount of collected light including dark field scattering light within the collection pupil of the collection objective,

wherein the one or more mask elements in the second configuration block a first portion of the second amount of collected light and transmit a second portion of the second amount of collected light, the second portion of the second amount of collected light selected by the one or more mask

elements in the second configuration from at least two spatially distinct locations in the collection pupil,

wherein at least one of the at least two spatially distinct locations selected by the one or more mask elements in the second configuration is different from at least one of the at least two spatially distinct locations selected by the one or more mask elements in the first configuration,

wherein the imaging detector is further configured to detect a second interference pattern formed by the second portion of the second amount of collected light; and

wherein the computing system is further configured to:

receive an output signal indicative of the second interference pattern;

determine a second phase difference between the transmitted light selected by the one or more mask elements in the second configuration from a first location of the at least two spatially distinct locations and the transmitted light selected by the one or more mask elements in the second configuration from a second location of the at least two spatially distinct locations from the second interference pattern; and

classify a defect located at the measurement spot based on the first and second phase differences.

3. The system of Claim 2, wherein the classifying of the defect involves determining a material composition of the defect based on the first and second phase differences.

4. The system of Claim 1, wherein the determining of the first phase difference involves a Fast Fourier Transform (FFT) analysis of the first interference pattern.

5. The system of Claim 1, wherein the determining of the first phase difference involves an iterative fit of a physical model of the measurement to the first interference pattern.

6. The system of Claim 1, wherein a spatial separation between the first location of the at least two spatially distinct locations in the collection pupil and the second location of the at least two spatially distinct locations in the collection pupil spans a range of NA from 0.1 to 0.9.

7. The system of Claim 1, wherein the first location of the at least two spatially distinct locations in the collection pupil and the second location of the at least two spatially distinct locations in the collection pupil are symmetrically located about a center of the collection pupil.

8. The system of Claim 1, wherein a size of a first aperture opening formed by the one or more mask elements in the first configuration at the first location of the at least two spatially distinct locations in the collection pupil is in a range from $0.01NA$ to $0.3NA$ and a size of a second aperture opening formed by the one or more mask elements in the first configuration at the the second location of the at least two spatially distinct locations in the collection pupil are symmetrically located about a

center of the collection pupil is in a range from $0.01NA$ to $0.3NA$.

9. The system of Claim 8, wherein the size of the first aperture opening is different from the size of the second aperture opening.

10. The system of Claim 8, further comprising:

a neutral density filter disposed in an optical path of the transmitted light selected by the one or more mask elements in the first configuration at or near the first location where the first aperture opening is formed by the one or more mask elements.

11. The system of Claim 1, further comprising:

a first actuator coupled to a first mask element of the one or more mask elements, the first actuator communicatively coupled to the computing system, wherein the first actuator moves the first mask element to a first desired position in response to a first control command communicated from the computing system to the first actuator.

12. The system of Claim 11, further comprising:

a second actuator coupled to a second mask element of the one or more mask elements, the second actuator communicatively coupled to the computing system, wherein the second actuator moves the second mask element to a second desired position in response to a second control command communicated from the computing system to the second actuator.

13. The system of Claim 1, the collection objective having a Numerical Aperture (NA) spanning at least a range from 0.1 NA to 0.99 NA.

14. The system of Claim 1, the computing system further configured to:

determine a difference between the first phase difference and a known value of phase difference associated with the specimen; and

store the difference value in a memory as a correction factor applicable to subsequent phase difference measurements performed by the system using the one or more mask elements in the first configuration.

15. A method comprising:

generating a first amount of illumination light directed to a measurement spot on a surface of a specimen;

collecting a first amount of collected light from the measurement spot on the surface of the specimen in response to the first amount of illumination light, the first amount of collected light including dark field scattering light within a collection pupil of a collection objective;

blocking a first portion of the first amount of collected light;

transmitting a second portion of the first amount of collected light, the second portion of the first amount of collected light selected by one or more mask elements in the first configuration from at least two spatially distinct locations in the collection pupil;

detecting a first interference pattern formed by the second portion of the first amount of collected light at or

near a field plane conjugate to the surface of the specimen; and

determining a first phase difference between the transmitted light selected by the one or more mask elements in the first configuration from a first location of the at least two spatially distinct locations and the transmitted light selected by the one or more mask elements in the first configuration from a second location of the at least two spatially distinct locations from the first interference pattern.

16. The method of Claim 15, further comprising:

generating a second amount of illumination light directed to the measurement spot on the surface of the specimen;

collecting a second amount of collected light from the measurement spot on the surface of the specimen in response to the second amount of illumination light, the second amount of collected light including dark field scattering light within the collection pupil of the collection objective;

blocking a first portion of the second amount of collected light;

transmitting a second portion of the second amount of collected light, the second portion of the second amount of collected light selected by one or more mask elements in a second configuration from at least two spatially distinct locations in the collection pupil, wherein at least one of the at least two spatially distinct locations selected by the one or more mask elements in the second configuration is different from at least one of the at least two

spatially distinct locations selected by the one or more mask elements in the first configuration;

detecting a second interference pattern formed by the second portion of the second amount of collected light at or near the field plane conjugate to the surface of the specimen;

determining a second phase difference between the transmitted light selected by the one or more mask elements in the second configuration from a first location of the at least two spatially distinct locations and the transmitted light selected by the one or more mask elements in the second configuration from a second location of the at least two spatially distinct locations from the second interference pattern; and

classifying a defect located at the measurement spot based on the first and second phase differences.

17. The method of Claim 16, wherein the classifying of the defect involves determining a material composition of the defect based on the first and second phase differences.

18. The method of Claim 15, wherein the determining of the first phase difference involves a Fast Fourier Transform (FFT) analysis of the first interference pattern.

19. The method of Claim 15, wherein the determining of the first phase difference involves an iterative fit of a physical model of the measurement to the first interference pattern.

20. The method of Claim 15, further comprising:
determining a difference between the first phase difference and a known value of phase difference associated with the specimen; and
storing the difference value in a memory as a correction factor applicable to subsequent phase difference measurements using the one or more mask elements in the first configuration.

21. A system comprising:
an illumination source configured to generate a first amount of illumination light directed to a measurement spot on a surface of a specimen;
a collection objective configured to collect a first amount of collected light from the measurement spot on the surface of the specimen in response to the first amount of illumination light, the first amount of collected light including dark field scattering light within a collection pupil of the collection objective;
one or more mask elements in a first configuration located at or near a pupil plane of the collection objective, a pupil plane conjugate to the pupil plane of the collection objective, or any combination thereof, the one or more mask elements in the first configuration block a first portion of the first amount of collected light and transmit a second portion of the first amount of collected light, the second portion of the first amount of collected light selected by the one or more mask elements in the first configuration from at least two spatially distinct locations in the collection pupil;
an imaging detector having a photosensitive surface located at or near a field plane conjugate to the surface

of the specimen, the imaging detector configured to detect a first interference pattern formed by the second portion of the first amount of collected light at or near the field plane; and

a non-transitory, computer-readable medium storing instructions that, when executed by one or more processors, causes the one or more processors to:

receive an output signal indicative of the first interference pattern; and

determine a first phase difference between the transmitted light selected by the one or more mask elements in the first configuration from a first location of the at least two spatially distinct locations and the transmitted light selected by the one or more mask elements in the first configuration from a second location of the at least two spatially distinct locations from the first interference pattern.

22. The system of Claim 21, further comprising:

one or more mask elements in a second configuration located at or near the pupil plane of the collection objective, the pupil plane conjugate to the pupil plane of the collection objective, or any combination thereof,

wherein the illumination source is further configured to generate a second amount of illumination light directed to the measurement spot on the surface of the specimen,

wherein the collection objective is further configured to collect a second amount of collected light from the measurement spot on the surface of the specimen in response to the second amount of illumination light, the second amount of collected light including dark field scattering

light within the collection pupil of the collection objective,

wherein the one or more mask elements in the second configuration block a first portion of the second amount of collected light and transmit a second portion of the second amount of collected light, the second portion of the second amount of collected light selected by the one or more mask elements in the second configuration from at least two spatially distinct locations in the collection pupil,

wherein at least one of the at least two spatially distinct locations selected by the one or more mask elements in the second configuration is different from at least one of the at least two spatially distinct locations selected by the one or more mask elements in the first configuration,

wherein the imaging detector is further configured to detect a second interference pattern formed by the second portion of the second amount of collected light; and

wherein the non-transitory, computer-readable medium further storing instructions that, when executed by the one or more processors, causes the one or more processors to:

receive an output signal indicative of the second interference pattern;

determine a second phase difference between the transmitted light selected by the one or more mask elements in the second configuration from a first location of the at least two spatially distinct locations and the transmitted light selected by the one or more mask elements in the second configuration from a second location of the at least two spatially distinct locations from the second interference pattern; and

classify a defect located at the measurement spot
based on the first and second phase differences.