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(71) Applicant: **KLA CORPORATION** [US/US]; One Technology Drive, Milpitas, California 95035 (US).

(72) Inventors: **VIRK, Kuljit S.**; 42667 Fontainebleau Park Lane, Fremont, California 94538 (US). **ZHOU, Minchuan**; 202 Houret Drive, Milpitas, California 95035 (US). **BHATTACHARYA, Indrasen**; One Technology Drive, Milpitas, California 95035 (US). **SEZGINER, Abdurrahman**; 19020 Withey Road, Monte Sereno, California 95030 (US).

(74) Agent: **MCANDREWS, Kevin** et al.; KLA CORPORATION, Legal Department, One Technology Drive, Milpitas, California 95035 (US).

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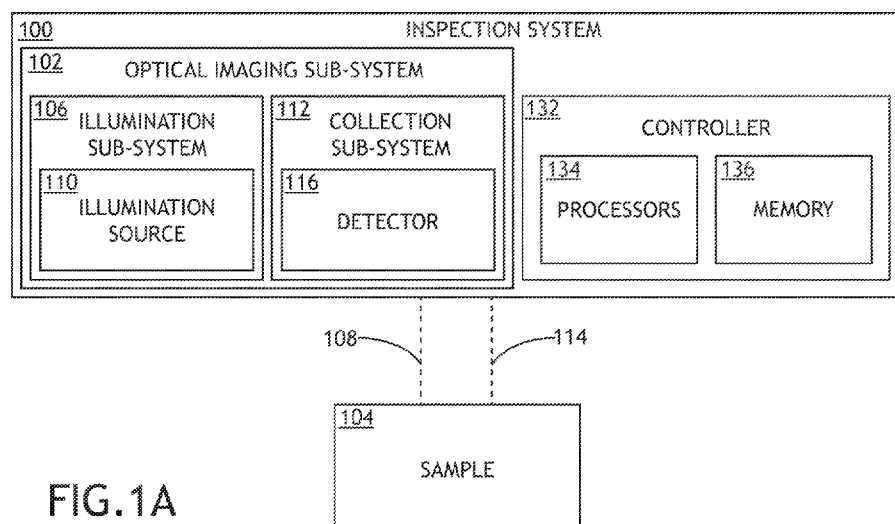


FIG. 1A

(57) Abstract: An inspection system may develop an inspection recipe by generating N inspection images of a preliminary sample with one or more optical inspection sub-systems associated with N different optical inspection modes, generating probabilities that each of the locations of the preliminary sample are in background or defect classes using a classifier with the inspection images from at least some combinations of a number M of the optical inspection modes, where M is greater than one and less than N and corresponds to a number of the optical inspection modes to include in the inspection recipe, and selecting one of the combinations of M of the optical inspection modes based on a metric describing a distinction between the background and defect classes. The inspection system may further identify defects on a test sample using M inspection images generated with the selected combination of M of the optical inspection modes.

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MULTI-MODE OPTICAL INSPECTION

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Application Serial Number 63/326,268, filed March 31, 2022, which is incorporated herein by reference in the entirety.

TECHNICAL FIELD

[0002] The present disclosure relates generally to defect inspection and, more particularly, to defect inspection using multiple optical modes.

BACKGROUND

[0003] Inspection systems are typically used in semiconductor fabrication processes to identify defects of the fabrication process that may result in performance degradation or failure of a fabricated device. As fabricated feature sizes continue to shrink, the sizes of fabrication defects also shrink. This results in weaker measurable signals associated with such defects and lower signal to noise ratios (SNRs) during defect inspection. There is therefore a need to develop systems and methods to address the above deficiencies.

SUMMARY

[0004] An inspection system is disclosed, in accordance with one or more illustrative embodiments. In one illustrative embodiment, the system includes a controller. In another illustrative embodiment, the controller develops an inspection recipe by N inspection images of a preliminary sample with one or more optical inspection sub-systems associated with N different optical inspection modes, generating probabilities that each of the locations of the preliminary sample are in background or defect classes using a classifier with the inspection images from at least some combinations of a number M of

the optical inspection modes, where M is greater than one and less than N and corresponds to a number of the optical inspection modes to include in the inspection recipe, and selecting one of the combinations of M of the optical inspection modes based on a metric describing a distinction between the background and defect classes. In another illustrative embodiment, the controller may identify defects on a test sample using M inspection images of the test sample generated based on the inspection recipe with the selected combination of M of the optical inspection modes.

[0005] An inspection system is disclosed, in accordance with one or more illustrative embodiments. In one illustrative embodiment, the system includes one or more optical inspection sub-systems and a controller. In another illustrative embodiment, the controller develops an inspection recipe by receiving N inspection images of a preliminary sample from the one or more optical inspection sub-systems associated with N different optical inspection modes, generating probabilities that each of the locations of the preliminary sample are in background or defect classes using a classifier with the inspection images from at least some combinations of a number M of the optical inspection modes, where M is greater than one and less than N and corresponds to a number of the optical inspection modes to include in the inspection recipe, and selecting one of the combinations of M of the optical inspection modes based on a metric describing a distinction between the background and defect classes. In another illustrative embodiment, the controller may identify defects on a test sample using M inspection images of the test sample generated based on the inspection recipe with the selected combination of M of the optical inspection modes.

[0006] An inspection method is disclosed, in accordance with one or more illustrative embodiments. In one illustrative embodiment, the method includes developing an inspection recipe by receiving N inspection images of a preliminary sample from the one or more optical inspection sub-systems associated with N different optical inspection modes, generating probabilities that each of the locations of the preliminary sample are in background or defect classes using a classifier with the inspection images from at least some combinations of a number M of the optical inspection modes, where M is greater than one and less than N and corresponds to a number of the optical inspection modes

to include in the inspection recipe, and selecting one of the combinations of M of the optical inspection modes based on a metric describing a distinction between the background and defect classes. In another illustrative embodiment, the method includes identifying defects on a test sample using M inspection images of the test sample generated based on the inspection recipe with the selected combination of M of the optical inspection modes.

[0007] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not necessarily restrictive of the invention as claimed. The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention and together with the general description, serve to explain the principles of the invention.

BRIEF DESCRIPTION OF DRAWINGS

[0008] The numerous advantages of the disclosure may be better understood by those skilled in the art by reference to the accompanying figures.

[0009] FIG. 1A is a block diagram of an inspection system, in accordance with one or more embodiments of the present disclosure.

[0010] FIG. 1B is a simplified schematic view of an optical imaging sub-system, in accordance with one or more embodiments of the present disclosure.

[0011] FIG. 2A is a flow diagram illustrating steps performed in an inspection method, in accordance with one or more embodiments of the present disclosure.

[0012] FIG. 2B is a flow diagram illustrating steps associated with the inspection method, in accordance with one or more embodiments of the present disclosure.

[0013] FIG. 2C is a flow diagram illustrating steps associated with the inspection method, in accordance with one or more embodiments of the present disclosure.

[0014] FIG. 3A is a simulated point cloud associated with background and defect probabilities for a particular defect type identified by an LDA technique using simulated optical inspection images from two different optical modes generated with a primary mode selected based on the SNR, in accordance with one or more embodiments of the present disclosure.

[0015] FIG. 3B is a histogram of the probability density function (PDF) of the background and defect classes along line in FIG. 3A, in accordance with one or more embodiments of the present disclosure. For example, the line may be associated with a linear transformation of the point cloud coordinates that best separates the two classes.

[0016] FIG. 3C is a simulated point cloud associated with background and defect probabilities for the particular defect type identified by an LDA technique using simulated optical inspection images from two different optical modes generated based on analysis of all possible combinations of optical modes, in accordance with one or more embodiments of the present disclosure.

[0017] FIG. 3D is a histogram of the PDF of the background and defect classes along line in FIG. 3C, in accordance with one or more embodiments of the present disclosure.

[0018] FIG. 3E is a plot of receiver operating characteristics (ROC) for the multi-mode detection configurations in FIGS. 3A-3D as well as for single-mode operation, in accordance with one or more embodiments of the present disclosure.

[0019] FIG. 4 is a plot of defects captured versus nuisance for multi-mode inspection using a neural network and single-mode inspection, in accordance with one or more embodiments of the present disclosure.

DETAILED DESCRIPTION

[0020] Reference will now be made in detail to the subject matter disclosed, which is illustrated in the accompanying drawings. The present disclosure has been particularly shown and described with respect to certain embodiments and specific features thereof. The embodiments set forth herein are taken to be illustrative rather than limiting. It should

be readily apparent to those of ordinary skill in the art that various changes and modifications in form and detail may be made without departing from the spirit and scope of the disclosure.

[0021] Embodiments of the present disclosure are directed to systems and methods for defect inspection with multiple optical modes. As used herein, an optical mode refers to a combination of optical imaging parameters used to generate an image of a sample with an optical inspection tool (e.g., sub-system) such as, but not limited to, properties of an illumination beam incident on the sample (e.g., wavelength, polarization, incidence angle, spot size, spot shape, depth of focus, or the like) or properties of collected light (e.g., wavelength, polarization, collection angle, or the like). It is contemplated herein that defects on a sample may respond differently to imaging with different optical modes such that defect analysis or identification may be improved by considering images generated with different optical modes. Further, multi-mode inspection may facilitate the identification of defects with greater sensitivity than for a single inspection mode. In this way, multi-mode inspection may enable the identification of smaller and/or weaker defects than single-mode inspection.

[0022] Semiconductor devices are typically fabricated using a series of process steps such as, but not limited to, deposition of process layers and/or photoresists, photoresist exposure with a desired pattern, etching of the photoresist and/or underlying process layers, polishing, or the like. Variations of any of these processes, alone or in combination, may lead to variations of fabricated sample features. In a general sense, some sample variations may be acceptable and are deemed nuisances, while others may result in unacceptable performance degradation or device failure and are deemed defects of interest (DOIs).

[0023] Inspection tools may be used to inspect a sample for defects after selected process steps. For example, an inspection tool may generate an inspection image of a sample after a particular process step. Such an inspection image is then typically compared to a reference image to identify defects, where the defects are related to differences between the inspection and reference images. For example, the reference image may be

subtracted from the inspection image to generate a difference image, where features in the difference image correspond to defects (e.g., measurable sample variations). These defects may then be classified as DOIs or nuisances. While various types of inspection tools have been developed, optical inspection tools that generate an image based on illumination with a light source are commonly used for in-line inspection due to the relatively high throughput.

[0024] Some embodiments of the present disclosure are directed to methods for developing an inspection recipe for optical inspection, where the inspection recipe includes a selection of optical modes to be implemented during an inspection process. For example, developing an inspection recipe may include, but is not limited to, generating inspection images of a preliminary sample using multiple optical inspection modes and selecting a subset of these optical inspection modes for use during an inspection process. As an illustration, a series of N inspection images may be generated using N different optical inspection modes, where N is an integer and greater than a number of optical inspection modes to be selected for use during the inspection process. Then, a classification technique (e.g., an unsupervised classifier or a supervised classifier) may be separately applied to various combinations (e.g., subsets) of these inspection images to generate probabilities that each sample location represented by pixels in the inspection images are in background or defect classes based on the respective optical inspection modes. One of these combinations of multiple inspection images (e.g., associated with a combination of optical inspection modes) may then be selected for inclusion in the inspection recipe for inspection of future samples.

[0025] In this way, the process of developing the inspection recipe may identify a selected combination of optical modes that effectively distinguishes defects from background signals from a wide range of possible optical inspection modes. It is contemplated herein that such multi-mode inspection may provide substantially superior performance (e.g., discrimination between defects and background signals) than single-mode inspection techniques. Further, it may be the case that increasing the number of inspection modes may generally increase the inspection performance. However, it is further recognized herein that it may be desirable to balance a number of optical inspection modes used

during inspection, particularly if such multi-mode inspection requires multiple imaging scans and thus takes longer to perform. Accordingly, the systems and methods disclosed herein may be used to identify combinations of optical inspection modes that balance inspection performance with inspection throughput.

[0026] It is contemplated that the systems and methods disclosed herein may advantageously identify a combination of optical modes for multi-mode inspection based on full inspection results (e.g., a full set of inspection images including raw data from an inspection system) generated using the optical modes under consideration. This provides the benefit of multi-modal information at a recipe generation stage and may provide increased performance relative to existing techniques that may provide multi-mode recipe generation based on more limited information.

[0027] For example, some exiting techniques may perform a multi-mode analysis a limited dataset including defects identified by at least one optical mode under consideration. As an illustration, some existing techniques may perform a full inspection run in a single mode (e.g., a mode having a relatively high signal to noise ratio or other performance metric), identify potential defects based on this single mode inspection, generate patch images based on these pre-identified potential defects, reviewing the sites of these pre-identified potential defects using one or more additional modes, and performing a multi-mode analysis based on these pre-identified potential defects. However, empirical evidence shows that DOIs identified using such techniques may have limited success. In particular, such techniques may in practice be overwhelmed by nuisances (e.g., background signals) and/or may fail to identify real defects with weak signals since the initial inspection was performed with a single optical mode and is thus limited by the sensitivity of that single optical mode. Existing multi-mode inspection techniques are generally described in U.S. Patent Application Publication Number 2020/0025689 published on January 23, 2020, U.S. Patent Number 11,415,531 issued on August 16, 2022, and U.S. Patent No. 11,010,885 issued on May 18, 2021, all of which are incorporated herein by reference in their entirety.

[0028] In contrast, systems and methods disclosed herein do not require that any particular optical mode identify any particular location as a defect when identifying a combination of optical modes for inclusion in an inspection recipe. Rather, systems and methods disclosed herein advantageously identify a combination of optical modes based on a multi-dimensional analysis of full inspection images from multiple modes. For example, probability maps may be generated based on a multi-dimensional analysis of complete inspection images from multiple modes. Such probability density maps may provide probabilities that each location on a sample (e.g., each pixel in aligned images from different modes) may belong to different classes (e.g., background or defect classes).

[0029] It is contemplated herein that a full inspection image with even a single optical mode may provide a vast amount of data (particularly for high-resolution inspection) such that considerations such as, but not limited to, memory storage or processing speed may impose practical limitations on the ability to simultaneously consider full inspection images from multiple modes. Such considerations may be one factor driving existing multi-mode techniques such as, but not limited to, multi-mode review of defects identified with at least one single-mode technique.

[0030] In some embodiments, full inspection images associated with all optical modes of interest (e.g., N optical modes) are generated, stored in memory, and subsequently analyzed in combination to determine a subset of optical modes (e.g., a combination of M optical modes, where M is less than N) to include in an inspection recipe for use during run-time based on a performance metric. It is noted that while M may generally have any value, it may be desirable to limit M to a relatively small number (e.g., 2-5) in some cases to balance the performance enhancement achieved through multi-mode inspection with inspection throughout considerations. Such a technique may be suitable for, but not limited to, cases where the hardware and/or time requirements are acceptable. In some embodiments, various possible combinations of M optical modes are evaluated and compared against each other to determine which combination provides superior performance according to the metric. Such a technique may reduce practical computation and/or storage issues, while maintaining the benefits of a full multi-mode analysis.

[0031] Any suitable metric may be utilized to select a combination of optical modes to include in an inspection recipe. In some embodiments, the metric is associated with an ability of the combination of optical modes to clearly distinguish background signals (e.g., nuisance data) from DOIs. As one illustration, the metric may be based on a separation of point clouds associated with different classifications (e.g., background or defect classes) in a multi-dimensional point cloud.

[0032] Any suitable classifier may be used to provide the probability maps within the spirit and scope of the present disclosure. In some embodiments, the classifier may include an unsupervised and/or a supervised classification technique. As an example, a supervised classifier may include a discriminant analysis technique (e.g., a linear discriminant analysis (LDA) technique, or the like), which may be suitable for cases when defects may be identified in one optical mode. As another example, an unsupervised classifier may include a soft clustering technique such as, but not limited to, Gaussian mixtures modeling. For instance, a point cloud may be generated using the selected inspection images for each combination considered, where the soft clustering technique generates probabilities that each pixel (or associated location on the sample of interest) may be classified in a particular class (e.g., background or defect classes). In this way, the metric used to select a combination of optical modes to include in the inspection recipe may be associated with a separation between clusters associated with background and defects in the point cloud. As another example, an unsupervised classifier includes a neural network. For instance, a neural network may accept inspection images from various optical inspection modes and generate probabilities that each pixel may be classified in background and defect classes. In this way, the output of the neural network may be substantially of the same type as other techniques (e.g., soft clustering based on point clouds, or the like). A neural network may also accept additional information for training purposes. For example, a neural network may accept design data (e.g., associated with patterned features on the sample) such that spatial relationships between pixels may be considered when determining probabilities that a particular pixel (and thus the corresponding location on the sample) is in background or defect classes.

[0033] Additional embodiments of the present disclosure are directed to methods for performing inspection with the inspection recipe once the combination of optical modes are identified.

[0034] Additional embodiments of the present disclosure are directed to inspection systems suitable for performing multi-mode optical inspection.

[0035] Referring now to FIGS. 1A-4, systems and methods for multi-mode optical inspection are described in greater detail, in accordance with one or more embodiments of the present disclosure.

[0036] FIG. 1A is a block diagram of an inspection system 100, in accordance with one or more embodiments of the present disclosure.

[0037] In one embodiment, the inspection system 100 includes one or more optical imaging sub-systems 102 (e.g., optical imaging tools) configured to generate one or more images of a sample 104, where the one or more optical imaging sub-systems 102 may be configurable to image the sample 104 with multiple optical inspection modes. For example, an optical imaging sub-system 102 may include an illumination sub-system 106 configured to illuminate the sample 104 with illumination 108 from an illumination source 110 and a collection sub-system 112 configured to generate an image of the sample 104 in response to light emanating from the sample (e.g., sample light 114) the illumination 108 using a detector 116.

[0038] An optical inspection mode may correspond to any combination of parameters associated with imaging the sample 104 including, but not limited to, properties of illumination directed to the sample 104 or light collected from the sample 104. The optical inspection modes are described in greater detail below.

[0039] The sample 104 may include a substrate formed of a semiconductor or non-semiconductor material (e.g., a wafer, or the like). For example, a semiconductor or non-semiconductor material may include, but is not limited to, monocrystalline silicon, gallium arsenide, and indium phosphide. The sample 104 may further include one or more layers disposed on the substrate. For example, such layers may include, but are not limited to,

a resist, a dielectric material, a conductive material, and/or a semiconductive material. Many different types of such layers are known in the art, and the term sample as used herein is intended to encompass a sample on which all types of such layers may be formed. One or more layers formed on a sample 104 may be patterned or unpatterned. For example, a sample may include a plurality of dies, each having repeatable patterned features. Formation and processing of such layers of material may ultimately result in completed devices. Many different types of devices may be formed on a sample, and the term sample as used herein is intended to encompass a sample on which any type of device known in the art is being fabricated.

[0040] The optical imaging sub-system 102 may generate one or more images of the sample 104 using any technique known in the art. In some embodiments, the optical imaging sub-system 102 is an optical imaging sub-system 102, where the illumination source 110 is an optical source configured to generate illumination 108 in the form of light, and where the collection sub-system 112 images the sample 104 based on light emanating from the sample 104.

[0041] Further, imaging with different optical inspection modes may generally be performed with any number of optical imaging sub-systems 102. In some embodiments, a single optical imaging sub-system 102 may be configured to image the sample 104 with multiple optical inspection modes simultaneously or sequentially. In some embodiments, different optical imaging sub-systems 102 are used to provide at least some different optical inspection modes.

[0042] FIG. 1B is a simplified schematic view of an optical imaging sub-system 102, in accordance with one or more embodiments of the present disclosure.

[0043] The illumination source 110 may include any type of illumination source known in the art suitable for generating an optical illumination 108, which may be in the form of one or more illumination beams. Further, the illumination 108 may have any spectrum such as, but not limited to, extreme ultraviolet (EUV) wavelengths, ultraviolet (UV) wavelengths, visible wavelengths, or infrared (IR) wavelengths. Further, the illumination source 110 may be a broadband source, a narrowband source, and/or a tunable source.

[0044] In some embodiments, the illumination source 110 includes a broadband plasma (BBP) illumination source. In this regard, the illumination 108 may include radiation emitted by a plasma. For example, a BBP illumination source 110 may include, but is not required to include, one or more pump sources (e.g., one or more lasers) configured to focus into the volume of a gas, causing energy to be absorbed by the gas in order to generate or sustain a plasma suitable for emitting radiation. Further, at least a portion of the plasma radiation may be utilized as the illumination 108.

[0045] In another embodiment, the illumination source 110 may include one or more lasers. For instance, the illumination source 110 may include any laser system known in the art capable of emitting radiation in the infrared, visible, or ultraviolet portions of the electromagnetic spectrum.

[0046] The illumination source 110 may further produce illumination 108 having any temporal profile. For example, the illumination source 110 may produce continuous-wave (CW) illumination 108, pulsed illumination 108, or modulated illumination 108. Additionally, the illumination 108 may be delivered from the illumination source 110 via free-space propagation or guided light (e.g., an optical fiber, a light pipe, or the like).

[0047] The illumination sub-system 106 and/or the optical imaging sub-system 102 may include various components to direct the illumination 108 to the sample 104 such as, but not limited to, lenses 118, mirrors, or the like. Further, such components may be reflective elements or transmissive elements. In this way, the depiction of the lenses 118 in FIG. 1B as transmissive elements is merely illustrative and not limiting. The illumination sub-system 106 may further include one or more optical elements 120 to modify and/or condition light in the associated optical path such as, but not limited to, one or more polarizers, one or more filters, one or more beam splitters, one or more diffusers, one or more homogenizers, one or more apodizers, or one or more beam shapers.

[0048] In some embodiments, the inspection system 100 includes a translation stage 122 for securing and/or positioning the sample 104 during imaging. For example, the translation stage 122 may include any combination of linear actuators, rotational

actuators, or angle actuators to position the sample 104 using any number of degrees of freedom.

[0049] The optical imaging sub-system 102 may include various components to collect at least a portion of the sample light 114 radiation emanating from the sample 104 (e.g., sample light in the case of an optical imaging sub-system 102) and direct at least a portion of the sample light to a detector 116 for generation of an image. An image generated by the inspection system 100 may be any type of image known in the art such as, but not limited to, a brightfield image, a darkfield image, a phase-contrast image, or the like. Further, images may be stitched together to form a composite image of the sample 104 or a portion thereof.

[0050] The inspection system 100 may further image the sample 104 using any technique known in the art. In some embodiments, the inspection system 100 generates an image of the sample 104 in a scanning mode by focusing the illumination 108 onto the sample 104 as a spot or a line, capturing a point or line image, and scanning the sample 104 to build up a two-dimensional image. In this configuration, scanning may be achieved by moving the sample 104 with respect to the illumination 108 (e.g., using the translation stage 122), by moving the illumination 108 with respect to the sample 104 (e.g., using actuable mirrors, or the like), or a combination thereof. In some embodiments, the inspection system 100 generates an image of the sample 104 in a static mode by directing the illumination 108 to the sample 104 in a two-dimensional field of view and capturing an two-dimensional image directly with the detector 116.

[0051] The optical imaging sub-system 102 may include various components to direct the sample light 114 to the detector 116 such as, but not limited to, lenses 124, mirrors, or the like. Further, such components may be reflective elements or transmissive elements. In this way, the depiction of the lenses 118 in FIG. 1B as transmissive elements is merely illustrative and not limiting. The optical imaging sub-system 102 may further include one or more optical elements 126 to modify and/or condition light in the associated optical path such as, but not limited to, one or more polarizers, one or more filters, one or more

beam splitters, one or more diffusers, one or more homogenizers, one or more apodizers, or one or more beam shapers.

[0052] The detector 116 may include any type of sensor known in the art suitable for measuring sample light 114. For example, a detector 116 may include a multi-pixel sensor such as, but not limited to, a charge-couple device (CCD), a complementary metal-oxide-semiconductor (CMOS) device, a line sensor, or a time-delay-integration (TDI) sensor. As another example, a detector 116 may include two or more single-pixel sensors such as, but not limited to, a photodiode, an avalanche photodiode, a photomultiplier tube, or a single-photon detector.

[0053] The illumination sub-system 106 and the optical imaging sub-system 102 may be configured in various ways within the spirit and scope of the present disclosure. In some embodiments, as illustrated in FIG. 1B, the inspection system 100 includes at least one beamsplitter 128 common to the optical paths of the illumination sub-system 106 and the optical imaging sub-system 102. In this way, the illumination sub-system 106 and the optical imaging sub-system 102 may both share a common objective lens 130 and may both utilize the full available pupil or Numerical Aperture (NA) provided by the objective lens 130. In some embodiments, though not shown, the illumination sub-system 106 and the optical imaging sub-system 102 may have separate optical paths without common elements.

[0054] In some embodiments, various alignment and/or stitching operations are performed on the data generated by the optical imaging sub-system 102 to form one or more images of the sample 104. As an example, in the case of a scanning system, data associated with multiple swaths or portions thereof may be aligned and/or stitched to form an image of the entire sample 104 or just a portion thereof. In this way, the term image is used herein to broadly describe any array of pixels representative of a portion of the sample 104 and is not intended to impart limitations associated with the imaging technique. An image may thus correspond to a full dataset provided by the optical imaging sub-system 102, may correspond to a sub-set of this data (e.g., a sub-image), or may correspond to multiple datasets that are stitched (and properly aligned).

[0055] In some embodiments, the inspection system 100 includes a controller 132, which may be communicatively coupled to the optical imaging sub-system 102 or any component therein. The controller 132 may include one or more processors 134 configured to execute program instructions maintained on a memory 136 (e.g., a memory medium). In this regard, the one or more processors 134 of controller 132 may execute any of the various process steps described throughout the present disclosure.

[0056] The one or more processors 134 of a controller 132 may include any processing element known in the art. In this sense, the one or more processors 134 may include any microprocessor-type device configured to execute algorithms and/or instructions. In one embodiment, the one or more processors 134 may consist of a desktop computer, mainframe computer system, workstation, image computer, parallel processor, or any other computer system (e.g., networked computer) configured to execute a program configured to operate the inspection system 100, as described throughout the present disclosure. It is further recognized that the term “processor” may be broadly defined to encompass any device having one or more processing elements, which execute program instructions from a non-transitory memory 136.

[0057] The memory 136 may include any storage medium known in the art suitable for storing program instructions executable by the associated one or more processors 134. For example, the memory 136 may include a non-transitory memory medium. By way of another example, the memory 136 may include, but is not limited to, a read-only memory, a random access memory, a magnetic or optical memory device (e.g., disk), a magnetic tape, a solid state drive and the like. It is further noted that memory 136 may be housed in a common controller housing with the one or more processors 134. In one embodiment, the memory 136 may be located remotely with respect to the physical location of the one or more processors 134 and controller 132. For instance, the one or more processors 134 of controller 132 may access a remote memory (e.g., server), accessible through a network (e.g., internet, intranet and the like). Therefore, the above description should not be interpreted as a limitation on the present invention but merely an illustration.

[0058] An optical inspection mode provided by the optical imaging sub-system 102 may be controlled based on control of any combination of components in the illumination sub-system 106 or the collection sub-system 112. For example, control of the illumination 108 directed to the sample 104 may be provided by the illumination source 110 directly and/or by optical elements 120 such as, but not limited to, a spectral filter to control a wavelength of the illumination 108, a polarizer to control a polarization of the illumination 108, or an apodizer (e.g., in an illumination pupil plane) to control an angular distribution of the illumination 108 on the sample 104. As another example, control of the sample light 114 collected from the sample 104 and passed to the detector 116 may be provided by optical elements 120 such as, but not limited to, a spectral filter to control a wavelength of the sample light 114 passed to the detector 116, a polarizer to control a polarization of the sample light 114 passed to the detector 116, or an apodizer (e.g., in a collection pupil plane) to control an angular distribution of the sample light 114 passed to the detector 116.

[0059] As an illustration, a particular optical inspection mode may correspond to illumination 108 with a selected spectrum (e.g., as described by a bandwidth and/or a central wavelength) and a selected polarization directed to the sample with a selected incidence angle (e.g., as defined by an illumination aperture or apodizer). The particular optical inspection mode may further correspond to a particular spectrum and polarization of the sample light 114 directed to the detector 116 (both of which may be the same or different than for the illumination 108 incident on the sample 104).

[0060] Further, the illumination source 110 and/or any of the optical elements 120 may be adjustable such that the inspection system 100 may be configured to provide different optical inspection modes. For example, any of the optical elements 120 may be directly tunable and/or controllable by actuators to provide different optical inspection modes. In some embodiments, the controller 132 generates drive signals for the illumination source 110 and/or any of the optical elements 120 to selectably provide different optical inspection modes.

[0061] In some embodiments, the inspection system 100 provides images with different optical inspection modes sequentially. For example, the inspection system 100 may sequentially switch between different optical imaging sub-systems 102 and/or adjust parameters of an optical imaging sub-system 102 to provide sequential images of the sample 104 with different optical inspection modes. As another example, an optical imaging sub-system 102 may be configured to simultaneously provide two or more images with different optical inspection modes simultaneously. As an illustration, an optical imaging sub-system 102 may include two or more collection channels, each having separate detector 116. The optical imaging sub-system 102 may then have one or more beamsplitters to split the sample light 114 into the various channels and/or additional optical elements 120 (e.g., separate spectral filters, polarizers, or the like) to provide separate control of the properties of the sample light 114 directed to the associated detector 116 in each channel.

[0062] FIG. 2A is a flow diagram illustrating steps performed in an inspection method 200, in accordance with one or more embodiments of the present disclosure. Applicant notes that the embodiments and enabling technologies described previously herein in the context of the inspection system 100 should be interpreted to extend to the method 200. It is further noted, however, that the method 200 is not limited to the architecture of the inspection system 100. In some embodiments, the controller 132 is configured to develop an inspection recipe using the method 200 or any steps therein.

[0063] In some embodiments, the method 200 includes a step 202 of developing an inspection recipe. In some embodiments, the method 200 includes a step 204 of identifying defects on a test sample using the inspection recipe.

[0064] FIG. 2B is a flow diagram illustrating steps (e.g., sub-steps) associated with the step 202 of developing an inspection recipe, in accordance with one or more embodiments of the present disclosure. FIG. 2C is a flow diagram illustrating steps (e.g., substeps) associated with the step 204 of developing an inspection recipe, in accordance with one or more embodiments of the present disclosure.

[0065] In some embodiments, the step 202 of developing an inspection recipe includes the step 206 of generating N inspection images of a preliminary sample with one or more optical imaging sub-systems 102 associated with N different optical inspection modes. As described previously herein, an optical inspection mode may include any unique combination of optical imaging parameters of the one or more optical imaging sub-systems 102. For example, the optical inspection modes may include unique combinations of parameters associated with the illumination 108 and/or the sample light 114 used to generate images including, but not limited to, wavelength, polarization, or angle.

[0066] The step 206 may include generating any number of inspection images. In some embodiments, N is an integer greater than two. In some embodiments, N is an integer greater than 5, 10, 100, or more. For example, N may be greater than or equal to ten.

[0067] The N inspection images may be any type of images including, but not limited to, darkfield images or brightfield images. In some embodiments, the inspection images may be raw images from an optical imaging sub-system 102. In this configuration, the inspection images may include various patterned features on the sample 104. In some embodiments, the inspection images are difference images. For example, a difference image may be generated based on a difference (e.g., a subtraction) of a raw image and a reference image that may represent an ideal or reference. In this configuration, an inspection image may be representative of deviations of a raw image of a test region of interest from the reference. Such a reference image may be generated using any suitable technique. For example, a reference image may be generated using a single image of a reference region with a common design as the test region and that is known to be free of or expected to be free of defects. As another example, a reference image may be generated by combining (e.g., averaging, or the like) multiple images of multiple reference regions.

[0068] In some embodiments, the step 206 further includes registering and/or scaling the N inspection images. In this way, the N inspection images may have a common number

of pixels and each pixel of all inspection images may correspond to a common location on the preliminary sample.

[0069] In some embodiments, the step 202 of developing an inspection recipe includes the step 208 of generating probabilities that each of the locations of the preliminary sample are in background or defect classes using a classifier (e.g., an unsupervised and/or a supervised classifier) with the inspection images from at least some combinations of a number M of the optical inspection modes. Further, M may be an integer greater than one and less than N and correspond to a number of the optical inspection modes to include in the inspection recipe. As used herein, a background class may correspond to a class describing background signals that are not of interest during inspection (e.g., nuisances), whereas a defect class describes outliers or rare events that may be associated with physical variations on the sample. It is noted that this class of defects may generally include defects of interest (DOIs) that may impact device performance and possibly additional nuisance signals that generally do not impact device performance.

[0070] Additionally, it is noted that the classifier may generally provide probabilities associated with any number of classes, where the number of classes may be fixed or dynamically generated. For example, it may be the case that different types of defects on a sample 104 may be separately identifiable (e.g., distinguished) by the classifier. In this way, the classifier may generate probabilities associated with a single defect class describing all defects or multiple defect classes. For example, defect classes may correspond to, but are not limited to, different defect types, defect location, or impact on performance.

[0071] The process of generating probabilities that each of the locations of the preliminary sample are in background or defect classes may include generating a series of probability maps or probability density functions (PDFs) for each class. As an illustration, a PDF for a background class may provide a probability that each pixel of the N inspection images (corresponding to each associated location on the preliminary sample) is in the background class, while a PDF for a defect class may provide a probability that each pixel

(and each corresponding location) is in that defect class. Further, it is contemplated herein that an unsupervised technique may generally characterize data into any number of classes (e.g., a background class and any number of defect classes).

[0072] In some embodiments, the step 202 of developing an inspection recipe includes the step 210 of selecting one of the combinations of M of the optical inspection modes as a selected combination based on a metric describing a distinction between the background and defect classes. In this way, the steps 208 and 210 may select a combination of optical inspection modes (e.g., a set of optical inspection modes) suitable for differentiating between background and defect signals based on the metric. For example, a receiver operating characteristics (ROC) curve may be generated based on a threshold that classifies a detection, such as probability threshold. Area under the curve may be used as a scalar metric to order the mode combinations, with larger area indicating a more accurate result. As another example, the metric may be associated with misclassification error on known test data at a fixed true positive rate.

[0073] Put another way, the step 208 may include implementing the classifier (or different iterations of the classifier) multiple times using inspection images associated with different combinations of optical inspection modes. The step 210 may then include selecting of one of the analyzed combinations for inclusion in the inspection recipe based on its ability to discriminate between defect and background signals.

[0074] In a general sense, the total number of possible combinations of M optical inspection modes from a set of N possible optical inspection modes may be described by the binomial coefficient given in Equation (1):

$$\binom{N}{M} = \frac{N!}{M!(N-M)!} \quad (1)$$

[0075] As a simple illustration, applying Equation (1) with values of M = 2 and N = 50 results in a total of 1,225 possible combinations. It is thus contemplated herein that the number of possible combinations may become practically prohibitive and that a variety of factors may be considered when selecting the values of M, N, and the number of possible combinations considered in step 208.

[0076] For example, M corresponds to a number of optical inspection modes to be included in the inspection recipe and implemented whenever the inspection recipe is run. In this way, the value of M may be influenced by factors such as, but not limited to, the inspection throughput tolerances for the particular application and the particular one or more optical imaging sub-systems 102 utilized. As described previously herein, some optical imaging sub-systems 102 may be capable of generating images with multiple optical inspection modes simultaneously (e.g., via different collection channels), whereas some optical imaging sub-systems 102 may require multiple separate measurements (e.g., scans) to obtain images with different optical inspection modes. Accordingly, the number M may be, but is not required to be, selected to balance throughput with a performance increase obtained through multi-mode inspection. In some embodiments, the value of M equals two. In some embodiments, the value of M equals three. In some embodiments, the value of M is in a range of 3-5. In some embodiments, the value of M is higher than 5.

[0077] Further, the value of N corresponds to a number of optical inspection modes considered during development of the inspection recipe (e.g., step 202). In this way, the value of N may be influenced by factors such as, but not limited to, physical limitations of an optical imaging sub-system 102, time requirements associated with inspection recipe development, or computational requirements associated with inspection recipe development. For example, it may be the case that many optical modes associated with different narrowband wavelength spectra may be obtained using broadband illumination 108 from a broadband illumination source 110 (e.g., a BBP source, or the like). Further, additional variations of polarization, incidence angle, or the like may further increase the possible number of optical inspection modes that may theoretically be provided by an optical imaging sub-system 102. However, it may be the case that time or computational requirements may practically limit the number N selected when implementing the method 200 in a particular application.

[0078] Additionally, not all possible combinations of M optical inspection modes need necessarily be considered in step 208. In some embodiments, only a portion of the possible combinations of optical inspection modes for selected values of N and M are

considered in step 208 (e.g., provided as inputs to an unsupervised classifier to generate probabilities of background and defect classes based on the associated inspection images). For example, one or more primary modes may be selected such that all combinations of optical inspection modes considered in in step 208 include the one or more primary modes. It is contemplated herein that selecting one or more primary mode for inclusion in all combinations considered in step 208 may substantially reduce the time required to develop the inspection recipe (e.g., step 202 generally) while also providing superior inspection performance to single-mode inspection, though the exact performance improvement may be impacted by the selection of the one or more primary modes. The one or more primary modes may be selected based on any criteria such as, but not limited to, SNR associated with defect signals, image contrast, or any image quality metric.

[0079] Any classifier suitable for generating probabilities that each of the locations of the preliminary sample are in background or defect classes may be utilized in step 208. For example, the classifier, may include any type of machine learning technique such as, but not limited to, supervised and/or unsupervised machine learning techniques.

[0080] In some embodiments, the classifier includes a soft clustering technique such as, but not limited to a Gaussian mixtures model (GMM). For example, a GMM may generate a probability model in the M-dimensional space and may utilize an expectation maximization algorithm to iteratively define parameters associated with Gaussian distributions that describe various classes (or clusters) in an M-dimensional point cloud associated with the M optical inspection images in each considered combination. For example, the GMM may assign a negative log-likelihood (NLL) score

$$NLL(I(x)) = -\text{Log} \left(P(I(x)) \right) \quad (2)$$

where $P(I(x))$ is the probability of observing the intensity $I(x)$ at a pixel location x . The expectation maximization algorithm may then adjust the parameters of the probability model to maximize P or minimize NLL for the associated data. It is noted that this technique does not require labels and may beneficially be implemented in a relatively

short timescale and may thus enable retraining (e.g., repeated updating of the inspection recipe in the step 202) on a relatively short timescale such as, but not limited to, a few days depending on the hardware used.

[0081] In some embodiments, the classifier includes a supervised discriminant analysis technique such as, but not limited to, a linear discriminant analysis (LDA) technique. It is noted that an LDA technique may be appropriate when defect signals are found in one region of the M-dimensional space. Further, a supervised technique including, but not limited to, LDA may be trained based on inspection images generated using the associated optical modes labeled based on known information (e.g., known classes of interest (e.g., background or defect classes)). Such labels may correspond to individual pixels and/or groups of pixels corresponding to associated physical locations on training samples. For instance, such labels may optionally describe regions on a training sample having a size corresponding to the point spread function in the associated image.

[0082] FIGS 3A-3E depict performance simulations of an implementation based on a LDA classifier. It is to be understood, however, that FIGS. 3A-3E and the associated descriptions are provided solely for illustrative purposes and should not be interpreted as limiting.

[0083] FIG. 3A is a simulated point cloud associated with background and defect probabilities for a particular defect type identified by an LDA technique using simulated optical inspection images from two different optical modes (e.g., $M = 2$) generated with a primary mode selected based on the SNR, in accordance with one or more embodiments of the present disclosure. For example, SNR may be, but is not required to be, determined based on a ratio of a maximum gray level of an absolute value difference image at the location of an identified defect to the standard deviation of the same difference image. In this way, FIG. 3A may correspond to a selected combination of optical inspection modes (e.g., from step 210) out of N possible optical inspection modes, where one of the two optical inspection modes was preselected (e.g., as a primary optical inspection mode) based on having the best SNR and the second was selected (e.g., in step 210) to provide the best separation between the classes.

[0084] FIG. 3B is a histogram of the PDF of the background and defect classes along line 302 in FIG. 3A, in accordance with one or more embodiments of the present disclosure. For example, the line 302 may be associated with a linear transformation of the point cloud coordinates that best separates the two classes (e.g., a separatrix).

[0085] FIG. 3C is a simulated point cloud associated with background and defect probabilities for the particular defect type identified by an LDA technique using simulated optical inspection images from two different optical modes (e.g., $M = 2$) generated based on analysis of all possible combinations of optical modes, in accordance with one or more embodiments of the present disclosure. For example, FIG. 3C may correspond to a selected combination of optical inspection modes (e.g., from step 210) out of N possible optical inspection modes, where all of the possible combinations were considered and where this selected combination provided the best separation between the background and defect classes.

[0086] FIG. 3D is a histogram of the PDF of the background and defect classes along line 304 in FIG. 3C, in accordance with one or more embodiments of the present disclosure. For example, the line 304 may be associated with a linear transformation of the point cloud coordinates that best separates the two classes (e.g., a separatrix).

[0087] FIG. 3E is a plot of receiver operating characteristics (ROC) for the multi-mode detection configurations in FIGS. 3A-3D as well as for single-mode operation, in accordance with one or more embodiments of the present disclosure. In particular, line 306 corresponds to an ROC curve for the multi-mode configuration in FIGS. 3C and 3D in which all possible combinations of optical inspection modes were evaluated, line 308 corresponds to an ROC curve for the multi-mode configuration in FIGS. 3A and 3B in which a primary mode was selected based on SNR and associated combinations were evaluated, and line 310 corresponds to an ROC curve for single-mode detection selected based on SNR.

[0088] The ROC curves are created by changing a threshold of detection used to separate data into the different classes, where all events above the threshold become detections. The curves then include the fraction of true detections (e.g., an area above the threshold

in the defect histogram) as the capture rate versus the false detection rate (e.g., an area above the threshold in the background histogram) on the horizontal axis. For the single-mode case (line 310), this threshold may be a probability value (e.g., a value of the PDF associated with a defect). For the multi-mode cases, this threshold may correspond to a position of a line 312 perpendicular to the associated separatrix.

[0089] As illustrated in FIG. 3E, multi-mode inspection with a primary mode selected based on SNR (line 308) improves performance (e.g., reduces false positives for a given capture rate) by orders of magnitude relative to single-mode inspection (line 310), while multi-mode inspection in which all combinations of modes are considered (line 306) further reduces the false positive rate by multiple additional orders of magnitude.

[0090] Referring again generally to FIG. 2B, in some embodiments, the classifier includes a neural network (e.g., a generative neural network, or the like). It is contemplated herein that a neural network may generally accept any number of input channels and may generate relationships between the input data. In this way, a neural network may output probabilities that a particular pixel (and the associated location on a sample) may belong to any number of classes (e.g., background or defect classes). For instance, a neural network may generate PDFs and enable analysis similar to the illustrations in FIGS. 3A-3E for soft clustering techniques based on point clouds.

[0091] In some embodiments, the step 208 includes training or implementing neural networks based on inspection images from various combinations of optical inspection modes. The inspection images may include any combination of raw inspection images or difference images associated with each selected combination of optical inspection modes.

[0092] In some embodiments, the step 208 further includes training or implementing neural networks based on one or more additional channels of data. For example, the neural networks may also receive design data associated with the sample (e.g., the preliminary sample). In this way, the generated probabilities may be based at least in part on spatial relationships between pixels in the inspection images (e.g., spatial relationships between locations on the sample). As an illustration, it may be the case that certain defect

types may typically occur on or around certain patterned features. In this way, knowledge of the features may facilitate more accurate distinction between background and defects in these locations and/or distinction between defects of different types. As another illustration, certain defect types may typically have an extended size and thus take up multiple pixels of an inspection images. In this way, groupings of pixels may be considered when generating probabilities that any given pixel is in background or defect classes. It is further to be understood that these examples are purely illustrative and not limiting on the operation of a neural network.

[0093] The design data may be in any suitable format such as, but not limited to, design clips in the form of images providing a representation of expected features on the sample. Such data may be sourced from any location such as, but not limited to, a recording or a storage medium (e.g., memory 136). Further, the design data may have any desired level of detail. In some embodiments, the design data provided to a neural network includes relatively low-frequency design information (e.g., design information associated with spatial scales larger than a selected value, or the like). For instance, the design data may provide information about the sizes, shapes, and orientations of features on the sample while avoiding the introduction of high-frequency noise into the model.

[0094] FIG. 4 is a plot of defects captured versus nuisance (e.g., background) for multi-mode inspection using a neural network (line 402) and single-mode inspection (line 404), in accordance with one or more embodiments of the present disclosure. As shown in FIG. 4, multi-mode inspection using a neural network provided nearly 10 times fewer nuisances than single-mode inspection for this example.

[0095] Referring again to FIG. 2C, the step 204 of inspection a test sample using the inspection recipe developed in step 202 is described in greater detail, in accordance with one or more embodiments of the present disclosure.

[0096] In some embodiments, the step 204 of inspecting a test sample includes a step 212 of generating M inspection images of the test sample (e.g., using the one or more optical imaging sub-systems 102) with the selected combination of M of the optical inspection modes from the inspection recipe. Further, the M inspection images of the test

sample may be registered and/or scaled such that they have a common number of aligned pixels, where the pixels correspond to locations on the test sample.

[0097] In some embodiments, the step 204 of inspecting a test sample includes a step 214 of classifying the locations of the test sample into the background and defect classes based on the M inspection images and the classifier in the inspection recipe. For example, the selected classifier trained in step 208 to generate probabilities that each pixel belongs to background and defect classes may now be used in step 214 to classify the defects based on the background and defect classes. For instance, the selected classifier trained in step 208 may provide weights or equations describing the background and defect classes that are suitable for predicting defects in the new inspection images for the test sample.

[0098] In some cases, a classifier trained in step 202 and utilized in step 204 includes a fixed set of trained weights that simply propagates input images to results without any feedback. The weights may be simply applied on the input data to effect linear transformations and all non-linear activations are held to be identical to those at training. Put another way, the unsupervised classifier may be held in the state identical at the end of its training. In some cases, some of the weights in the trained classifier may be updated to account for variations within a particular test sample or between multiple test samples (e.g., wafer-wafer or within-wafer variations) as well as tool operating condition variations.

[0099] In some cases, the step 214 performs a soft classification and may generate probabilities that each pixel (and thus each corresponding location of the test sample) belongs to each of the background and defect classes. In some cases, the step 214 performs a hard classification and assigns each pixel into a single class (e.g., based on one or more thresholds applied to the probabilities).

[0100] Further, in applications in which the classifier includes a neural network, the step 214 may incorporate additional input channels associated with the test sample such as, but not limited to design data.

[0101] Referring again generally to FIG. 2A, it is contemplated herein that the techniques associated with the method 200 may be combined with additional unsupervised or supervised techniques for further discrimination between defects of interest and nuisance signals on a test sample. For example, defects identified on a test sample in step 214 may then be further analyzed with a supervised classifier. In some cases, defects identified in step 214 may be analyzed using an additional inspection tool such as, but not limited to a scanning electron microscope, to verify the classification. Such information may then be used as a label when training a supervised classifier.

[0102] The herein described subject matter sometimes illustrates different components contained within, or connected with, other components. It is to be understood that such depicted architectures are merely exemplary, and that in fact many other architectures can be implemented which achieve the same functionality. In a conceptual sense, any arrangement of components to achieve the same functionality is effectively "associated" such that the desired functionality is achieved. Hence, any two components herein combined to achieve a particular functionality can be seen as "associated with" each other such that the desired functionality is achieved, irrespective of architectures or intermedial components. Likewise, any two components so associated can also be viewed as being "connected" or "coupled" to each other to achieve the desired functionality, and any two components capable of being so associated can also be viewed as being "couplable" to each other to achieve the desired functionality. Specific examples of couplable include but are not limited to physically interactable and/or physically interacting components and/or wirelessly interactable and/or wirelessly interacting components and/or logically interactable and/or logically interacting components.

[0103] It is believed that the present disclosure and many of its attendant advantages will be understood by the foregoing description, and it will be apparent that various changes may be made in the form, construction, and arrangement of the components without departing from the disclosed subject matter or without sacrificing all of its material advantages. The form described is merely explanatory, and it is the intention of the following claims to encompass and include such changes. Furthermore, it is to be understood that the invention is defined by the appended claims.

CLAIMS

What is claimed:

1. An inspection system comprising:

a controller including one or more processors to execute program instructions causing the one or more processors to:

develop an inspection recipe with steps comprising:

receiving N inspection images of a preliminary sample from one or more optical inspection sub-systems associated with N different optical inspection modes, wherein N is an integer greater than two, wherein each of the N optical inspection modes is associated with unique optical imaging parameters of the one or more optical inspection sub-systems, wherein locations in the N inspection images of the preliminary sample correspond to locations on the preliminary sample;

generating probabilities that each of the locations of the preliminary sample are in background or defect classes using a classifier with the inspection images from at least some combinations of a number M of the optical inspection modes, wherein M is an integer greater than one and less than N and corresponds to a number of the optical inspection modes to include in the inspection recipe; and

selecting one of the combinations of M of the optical inspection modes as a selected combination based on a metric describing a distinction between the background and defect classes; and

identify defects on a test sample using M inspection images of the test sample generated based on the inspection recipe with the selected combination of M of the optical inspection modes.

2. The inspection system of claim 1, wherein identifying defects on the test sample using M inspection images of the test sample generated based on the inspection recipe with the selected combination of M of the optical inspection modes comprises:

classifying the locations of the test sample into the background and defect classes based on the M inspection images and the classifier in the inspection recipe.

3. The inspection system of claim 1, wherein developing the inspection recipe further includes registering the N inspection images of the preliminary sample.

4. The inspection system of claim 1, wherein the N inspection images of the preliminary sample have a common number of pixels.

5. The inspection system of claim 1, wherein the N inspection images of the preliminary sample and the M inspection images of the test sample correspond to raw images from the one or more optical inspection sub-systems.

6. The inspection system of claim 1, wherein the N inspection images of the preliminary sample and the M inspection images of the test sample correspond to difference images based on differences between raw images and reference images from the one or more optical inspection sub-systems.

7. The inspection system of claim 1, wherein the defect classes include a single defect class.

8. The inspection system of claim 1, wherein the defect classes include a two or more defect classes.

9. The inspection system of claim 1, wherein the classifier comprises:
an unsupervised classifier.

10. The inspection system of claim 9, wherein the unsupervised classifier implements a soft clustering technique.

11. The inspection system of claim 10, wherein the soft clustering technique comprises:

a Gaussian mixtures model (GMM) technique.

12. The inspection system of claim 1, wherein the classifier comprises:

a supervised classifier.

13. The inspection system of claim 12, wherein the supervised classifier implements linear discriminant analysis (LDA) technique.

14. The inspection system of claim 12, wherein the supervised classifier is trained on training data including at least one of labeled background or defect classes.

15. The inspection system of claim 1, wherein the classifier comprises:

a neural network.

16. The inspection system of claim 1, wherein generating probabilities that each of the locations of the preliminary sample are in background or defect classes using the classifier with the inspection images from at least some combinations of the number M of the optical inspection modes comprises:

generating probabilities that each of the locations of the preliminary sample are in background or defect classes using a neural network with the inspection images from at least some combinations of the number M of the optical inspection modes.

17. The inspection system of claim 1, wherein generating probabilities that each of the locations of the preliminary sample are in background or defect classes using the classifier with the inspection images from at least some combinations of the number M of the optical inspection modes comprises:

generating probabilities that each of the locations of the preliminary sample are in background or defect classes using the classifier with the inspection images from all of the combinations of the number M of the optical inspection modes

18. The inspection system of claim 1, wherein developing the inspection recipe further comprises:

selecting one of the optical inspection modes as a primary mode, wherein generating probabilities that each of the locations of the preliminary sample are in background or defect classes using the classifier with the inspection images from at least some combinations of the number M of the optical inspection modes comprises:

generating probabilities that each of the locations of the preliminary sample are in background or defect classes using the classifier with the inspection images from at least some of the combinations of the number M of the optical inspection modes that include the primary mode.

19. The inspection system of claim 1, wherein the N different optical inspection modes are associated with difference in at least one of an illumination wavelength, an illumination polarization, or an illumination angle.

20. The inspection system of claim 1, wherein the N different optical inspection modes are associated with difference in at least one of a wavelength, a polarization, or an angle of light collected by the one or more optical inspection sub-systems and directed to a detector.

21. The inspection system of claim 1, wherein M equals two.

22. The inspection system of claim 1, wherein N is greater than or equal to three.

23. An inspection system comprising:

one or more optical inspection sub-systems;

a controller communicatively coupled to the one or more optical inspection sub-systems, the controller including one or more processors to execute program instructions causing the one or more processors to:

develop an inspection recipe with steps comprising:

receiving N inspection images of a preliminary sample from one or more optical inspection sub-systems associated with N different optical inspection modes, wherein N is an integer greater than two, wherein each of the N optical inspection modes is associated with unique optical imaging parameters of the one or more optical inspection sub-systems, wherein locations in the N inspection images of the preliminary sample correspond to locations on the preliminary sample;

generating probabilities that each of the locations of the preliminary sample are in background or defect classes using a classifier with the inspection images from at least some combinations of a number M of the optical inspection modes, wherein M is an integer greater than one and less than N and corresponds to a number of the optical inspection modes to include in the inspection recipe; and

selecting one of the combinations of M of the optical inspection modes as a selected combination based on a metric describing a distinction between the background and defect classes; and

identify defects on a test sample using M inspection images of the test sample generated based on the inspection recipe with the selected combination of M of the optical inspection modes.

24. The inspection system of claim 23, wherein the one or more optical inspection sub-systems comprise:

two or more optical inspection sub-systems.

25. The inspection system of claim 23, wherein the one or more optical inspection sub-systems comprise:

a single optical inspection sub-system.

26. The inspection system of claim 23, wherein the N inspection images of the preliminary sample and the M inspection images of the test sample correspond to at least one of raw images from the one or more optical inspection sub-systems or difference images based

on differences between the raw images and reference images from the one or more optical inspection sub-systems.

27. The inspection system of claim 23, wherein the classifier comprises:
an unsupervised classifier.

28. The inspection system of claim 23, wherein the classifier comprises:
a supervised classifier.

29. The inspection system of claim 23, wherein the classifier comprises:
a neural network.

30. The inspection system of claim 23, wherein the N different optical inspection modes are associated with difference in at least one of an illumination wavelength, an illumination polarization, or an illumination angle.

31. The inspection system of claim 23, wherein the N different optical inspection modes are associated with difference in at least one of a wavelength, a polarization, or an angle of light collected by the one or more optical inspection sub-systems and directed to a detector.

32. An inspection method comprising:
developing an inspection recipe with steps comprising:
generating N inspection images of a preliminary sample with one or more optical inspection sub-systems associated with N different optical inspection modes, wherein N is an integer greater than two, wherein each of the N optical inspection modes is associated with unique optical imaging parameters of the one or more optical inspection sub-systems, wherein locations in the N inspection images of the preliminary sample correspond to locations on the preliminary sample;

generating probabilities that each of the locations of the preliminary sample are in background or defect classes using a classifier with the inspection images from at least some combinations of a number M of the optical inspection modes, wherein M is an integer greater than one and less than N and corresponds to a number of the optical inspection modes to include in the inspection recipe; and

selecting one of the combinations of M of the optical inspection modes as a selected combination based on a metric describing a distinction between the background and defect classes; and

identifying defects on a test sample using M inspection images of the test sample generated based on the inspection recipe with the selected combination of M of the optical inspection modes.

33. The inspection method of claim 32, wherein identifying defects on the test sample using M inspection images of the test sample generated based on the inspection recipe with the selected combination of M of the optical inspection modes comprises:

classifying the locations of the test sample into the background and defect classes based on the M inspection images and the classifier in the inspection recipe.

34. The inspection method of claim 32, wherein developing the inspection recipe further includes registering the N inspection images of the preliminary sample.

35. The inspection method of claim 32, wherein the N inspection images of the preliminary sample have a common number of pixels.

36. The inspection method of claim 32, wherein the N inspection images of the preliminary sample and the M inspection images of the test sample correspond to raw images from the one or more optical inspection sub-systems.

37. The inspection method of claim 32, wherein the N inspection images of the preliminary sample and the M inspection images of the test sample correspond to difference images

based on differences between raw images and reference images from the one or more optical inspection sub-systems.

38. The inspection method of claim 32, wherein the defect classes include a single defect class.

39. The inspection method of claim 32, wherein the defect classes include a two or more defect classes.

40. The inspection method of claim 32, wherein the classifier comprises:
an unsupervised classifier.

41. The inspection method of claim 32, wherein the classifier comprises:
a supervised classifier.

42. The inspection method of claim 32, wherein the classifier comprises:
a neural network.

43. The inspection method of claim 32, wherein generating probabilities that each of the locations of the preliminary sample are in background or defect classes using the classifier with the inspection images from at least some combinations of the number M of the optical inspection modes comprises:

generating probabilities that each of the locations of the preliminary sample are in background or defect classes using the classifier with the inspection images from all of the combinations of the number M of the optical inspection modes.

44. The inspection method of claim 32, wherein developing the inspection recipe further comprises:

selecting one of the optical inspection modes as a primary mode, wherein generating probabilities that each of the locations of the preliminary sample are in

background or defect classes using the classifier with the inspection images from at least some combinations of the number M of the optical inspection modes comprises:

generating probabilities that each of the locations of the preliminary sample are in background or defect classes using the classifier with the inspection images from at least some combinations of the number M of the optical inspection modes that include the primary mode.

45. The inspection method of claim 32, wherein the N different optical inspection modes are associated with difference in at least one of an illumination wavelength, an illumination polarization, or an illumination angle.

46. The inspection method of claim 32, wherein the N different optical inspection modes are associated with difference in at least one of a wavelength, a polarization, or an angle of light collected by the one or more optical inspection sub-systems and directed to a detector.

47. The inspection method of claim 32, wherein M equals two.

48. The inspection method of claim 32, wherein N is greater than or equal to three.

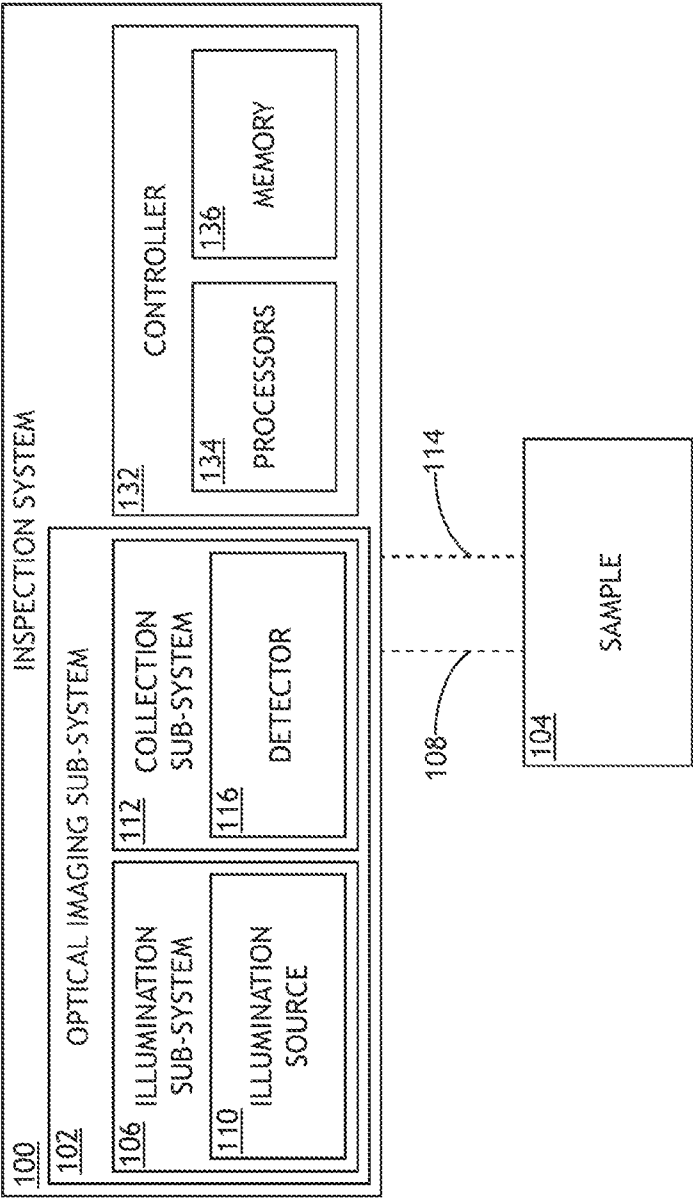


FIG.1A

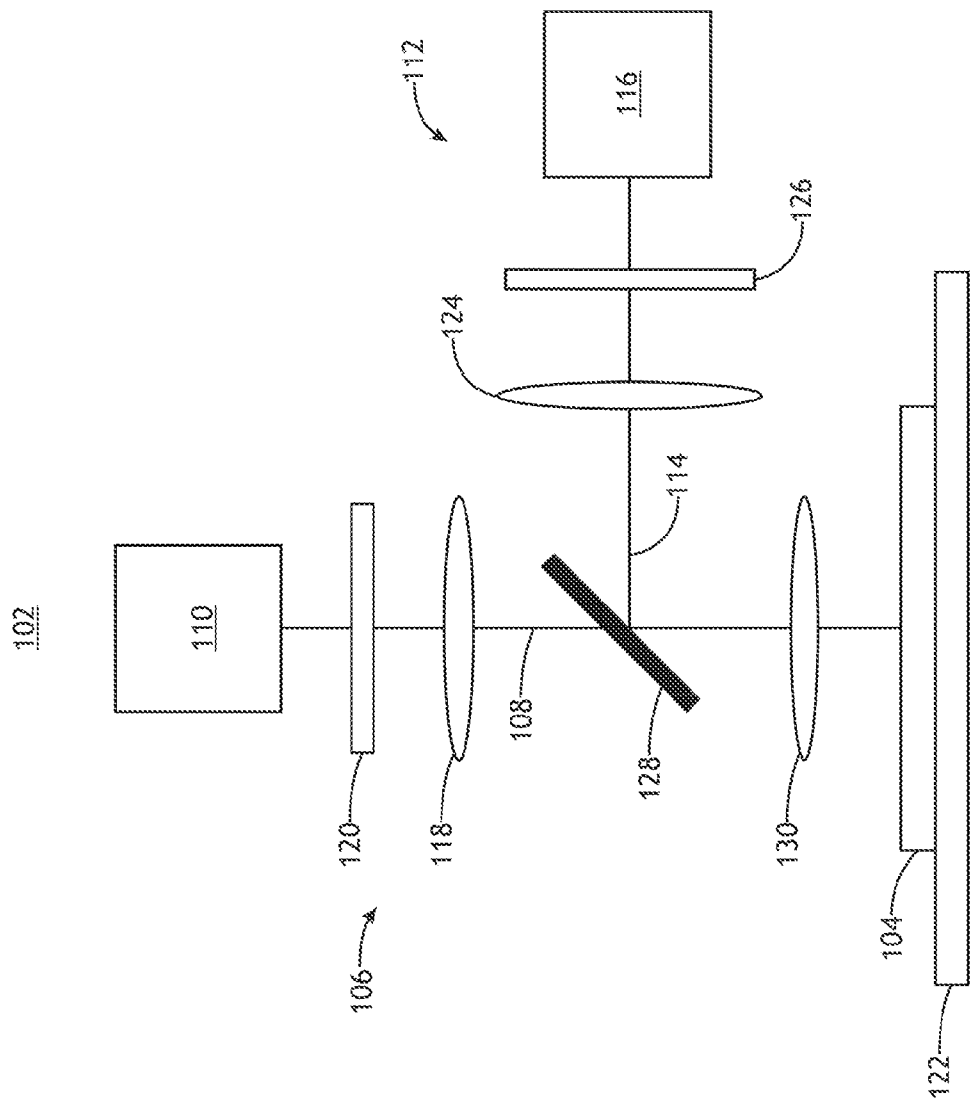


FIG.1B

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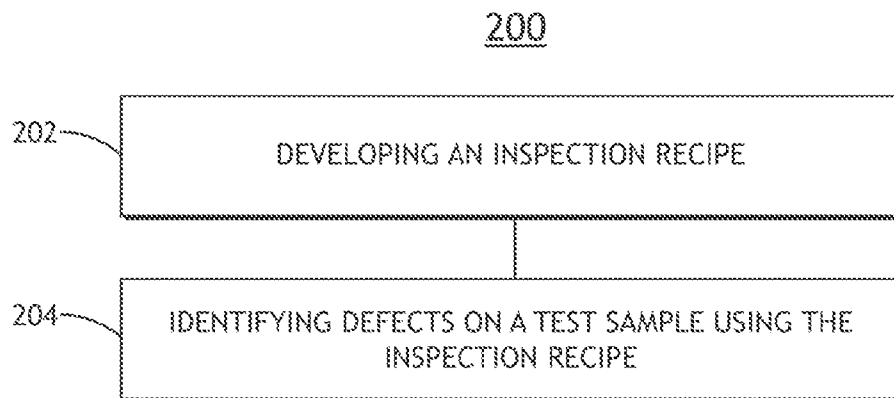


FIG.2A

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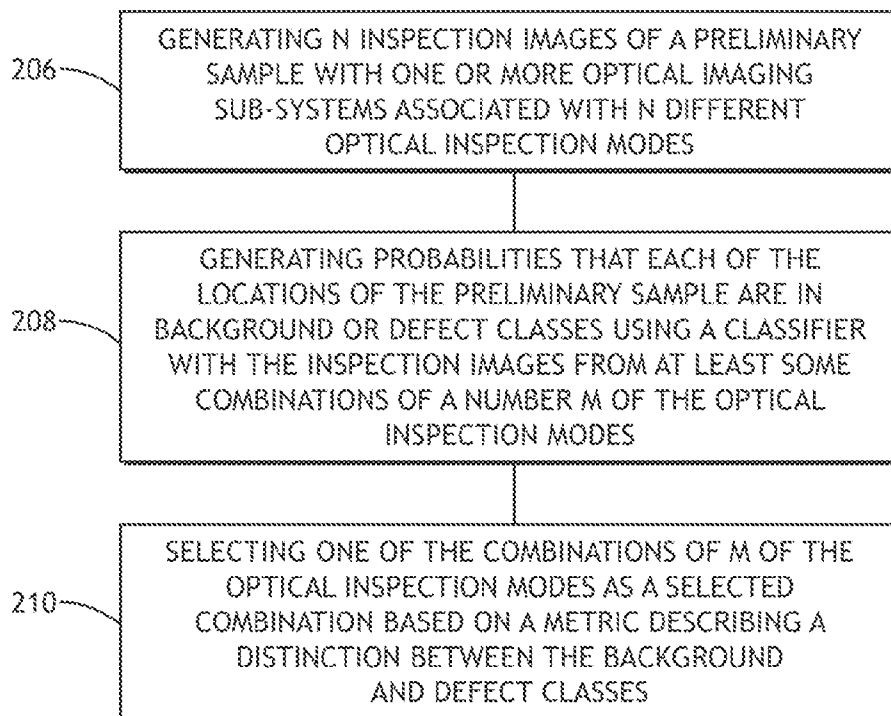
202

FIG.2B

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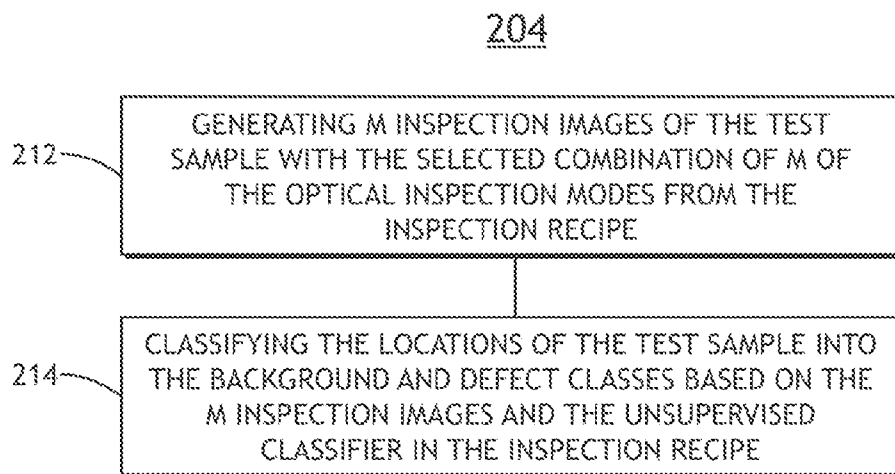


FIG.2C

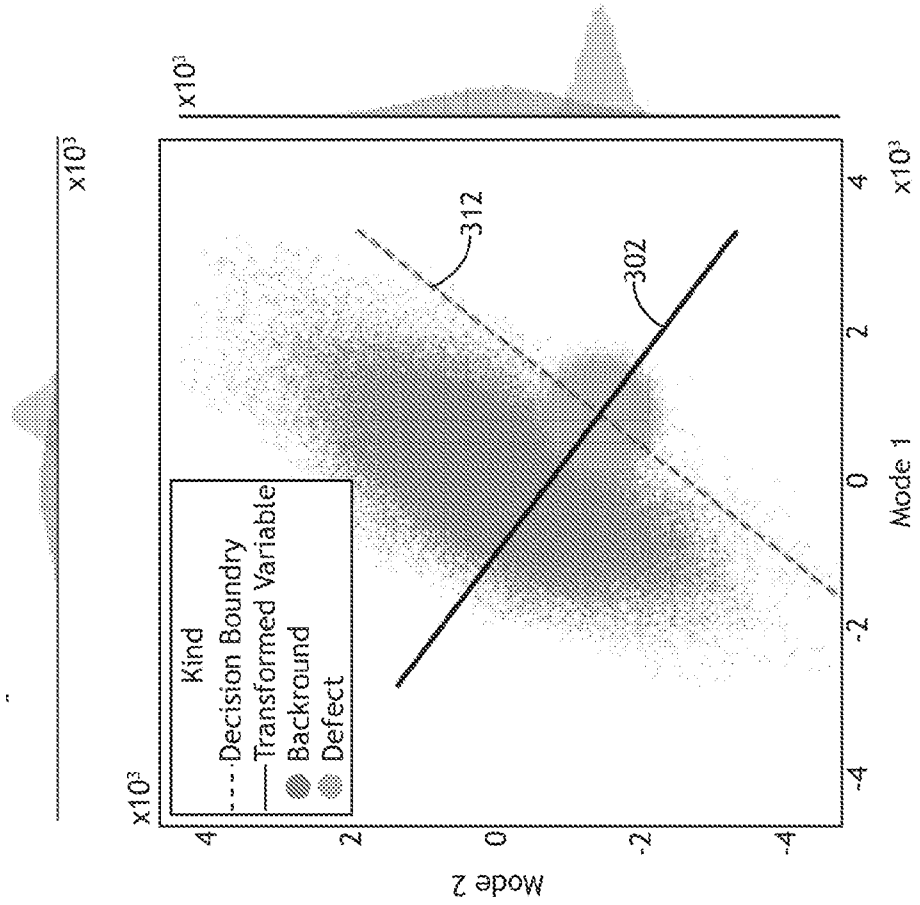


FIG.3A

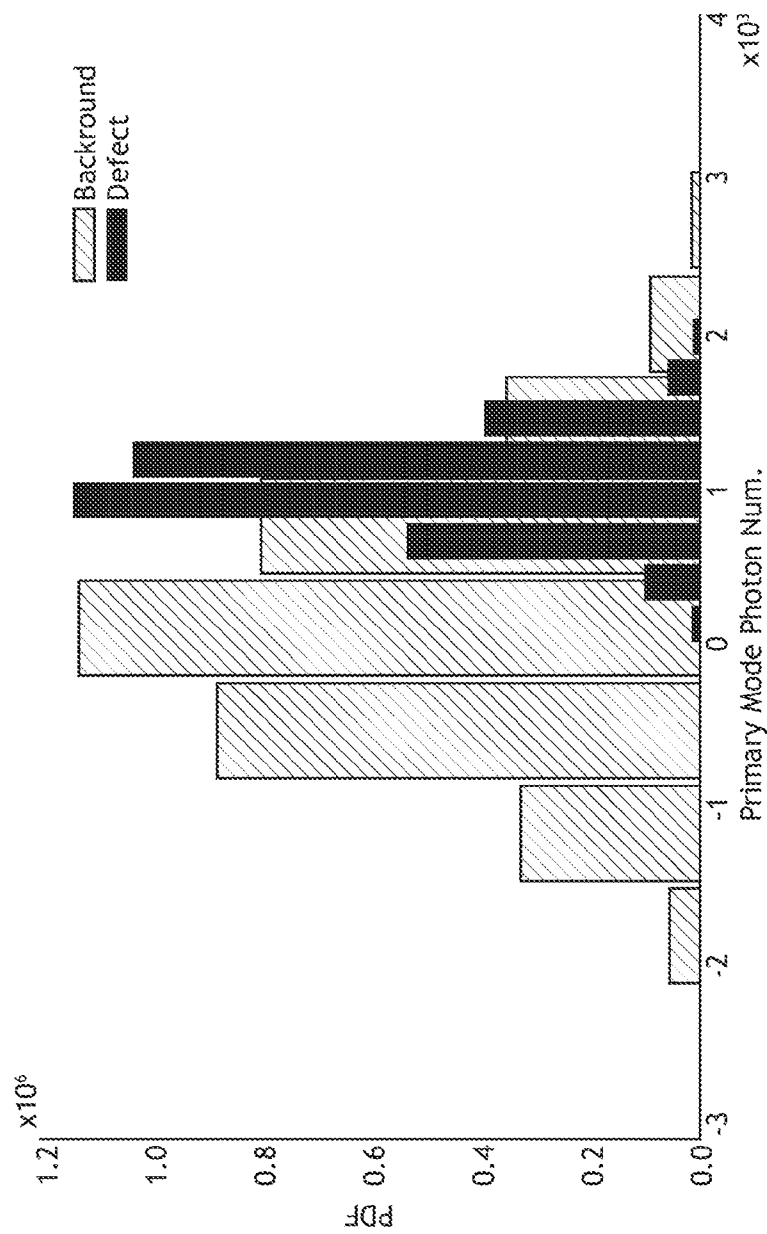


FIG.3B

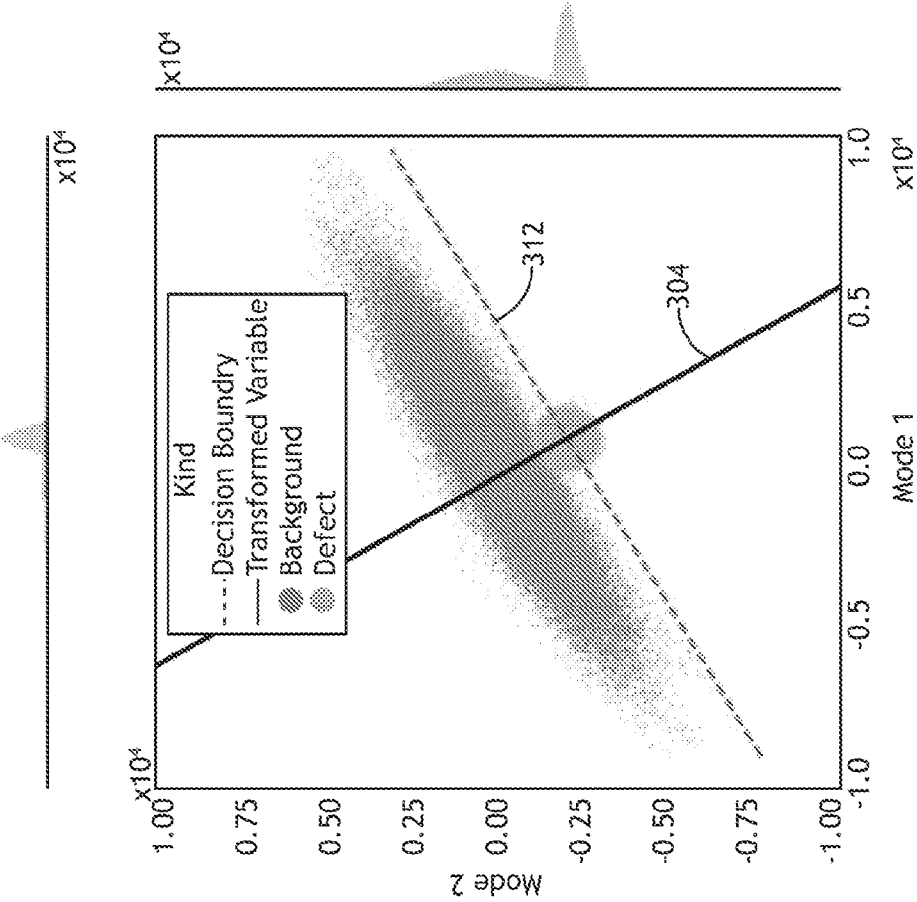


FIG.3C

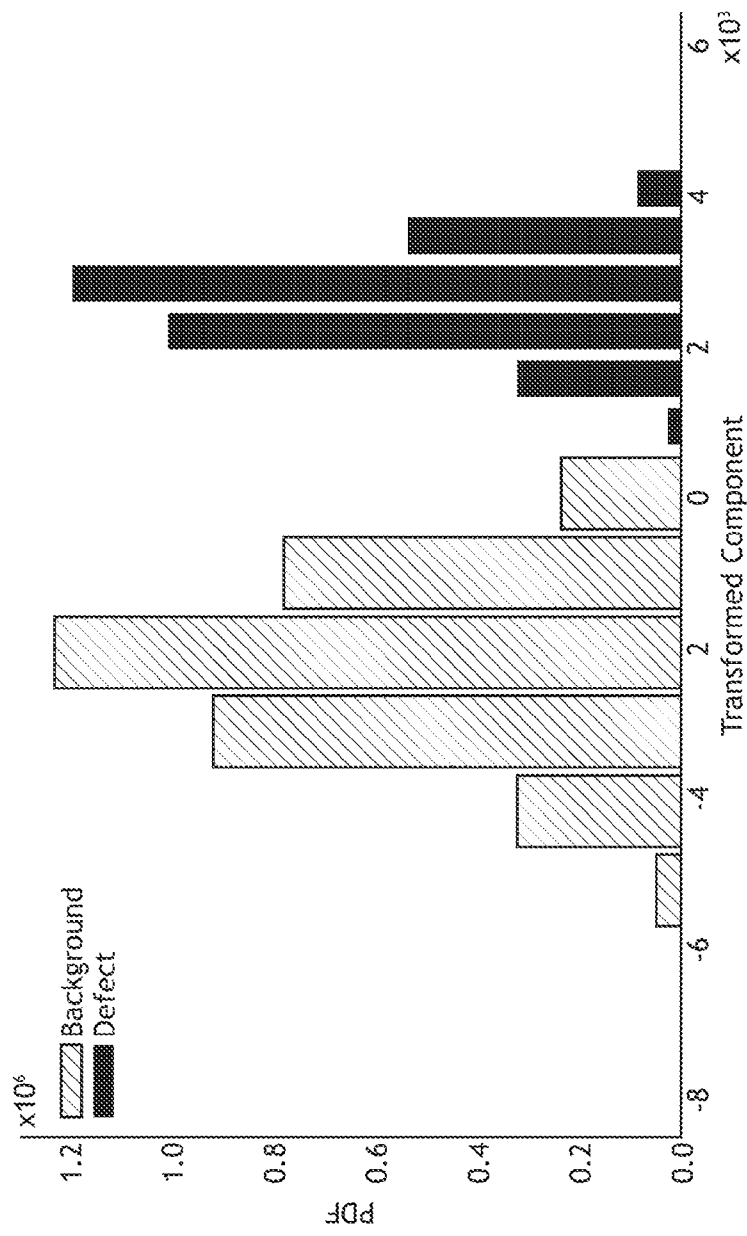


FIG.3D

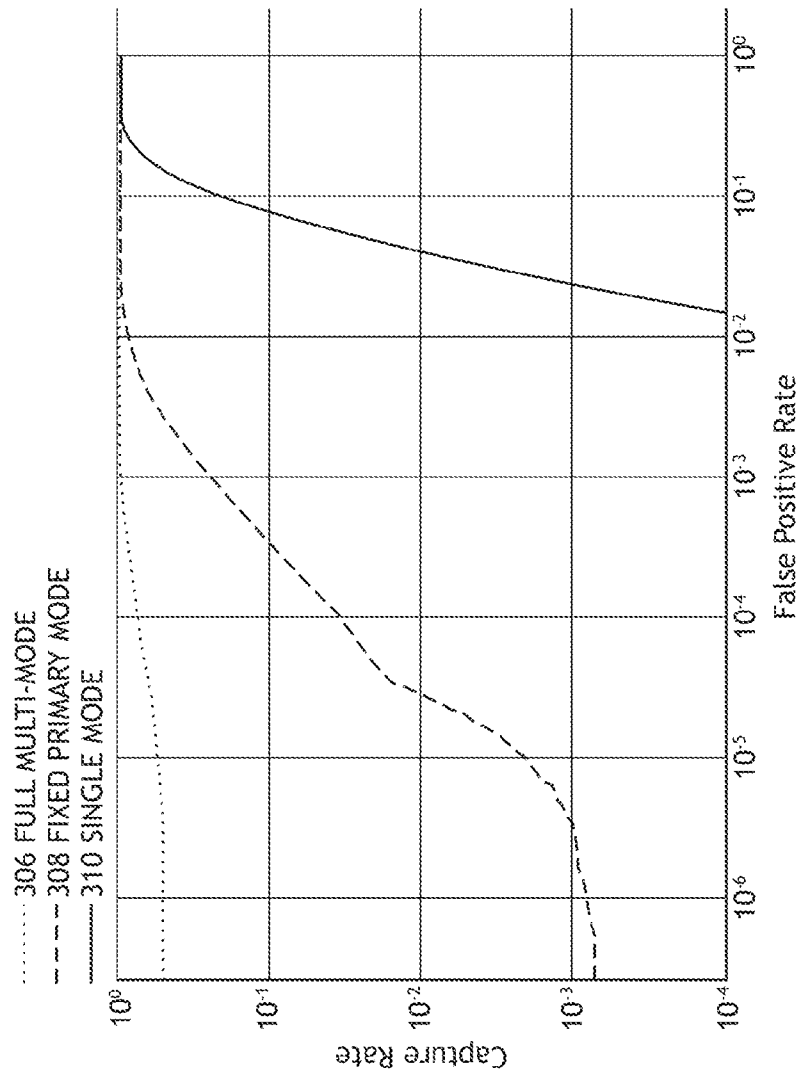


FIG.3E

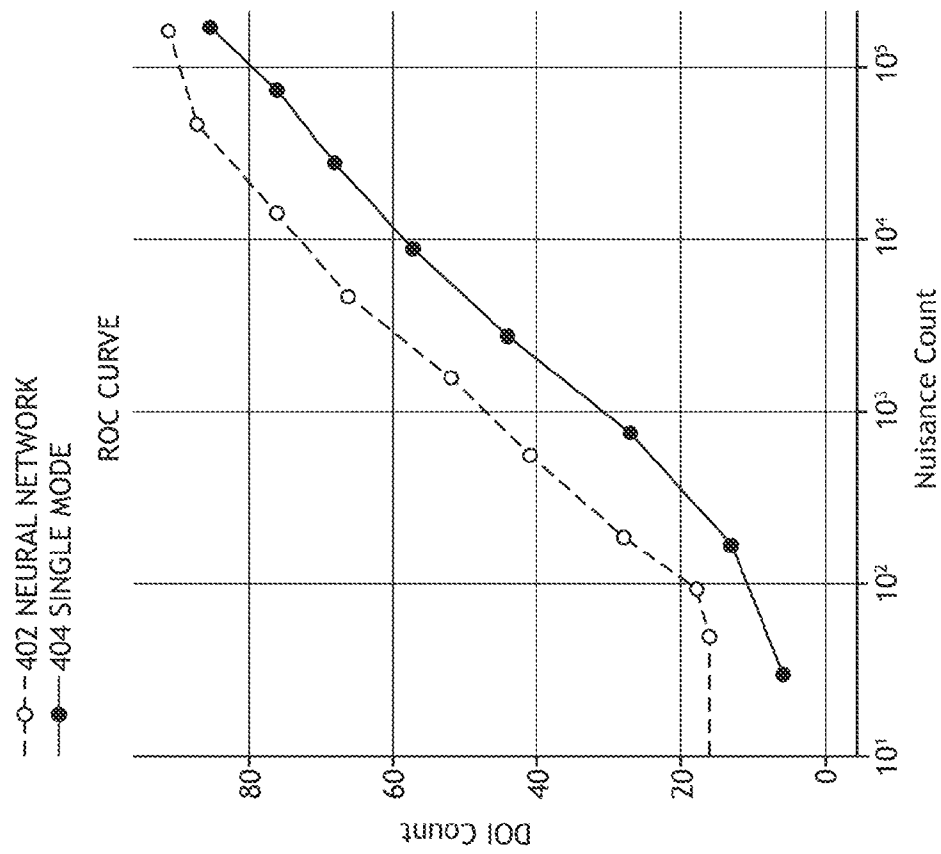


FIG.4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2023/017001

A. CLASSIFICATION OF SUBJECT MATTER

G01N 21/88(2006.01)i; G01N 21/95(2006.01)i; G06T 7/00(2006.01)i; H01L 21/66(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01N 21/88(2006.01); G01N 21/95(2006.01); G01N 21/956(2006.01); G06K 9/00(2006.01); G06K 9/62(2006.01); G06T 7/00(2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: multi-mode, recipe, Gaussian mixtures model (GMM), probability, background, nuisance

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2020-0193588 A1 (KLA-TENCOR CORPORATION) 18 June 2020 (2020-06-18) paragraphs [0014]-[0058] and figures 1-3	1-8,12-26,28-39,41-48
Y		9-11,27,40
Y	US 2022-0050061 A1 (APPLIED MATERIALS ISRAEL LTD.) 17 February 2022 (2022-02-17) paragraphs [0089], [0096] and claim 1	9-11,27,40
A	US 2009-0080759 A1 (BHASKAR et al.) 26 March 2009 (2009-03-26) claims 1-20	1-48
A	US 2015-0006103 A1 (KLA-TENCOR CORPORATION) 01 January 2015 (2015-01-01) paragraphs [0061]-[0063] and figure 3	1-48
A	US 2020-0025689 A1 (KLA-TENCOR CORPORATION) 23 January 2020 (2020-01-23) paragraphs [0015]-[0036] and figures 1, 3	1-48



Further documents are listed in the continuation of Box C.



See patent family annex.

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“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

24 July 2023

Date of mailing of the international search report

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Name and mailing address of the ISA/KR

Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon
35208, Republic of Korea

Facsimile No. +82-42-481-8578

Authorized officer

PARK, Tae Wook

Telephone No. +82-42-481-3405

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/US2023/017001

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				TW	202018281	A	16 May 2020
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