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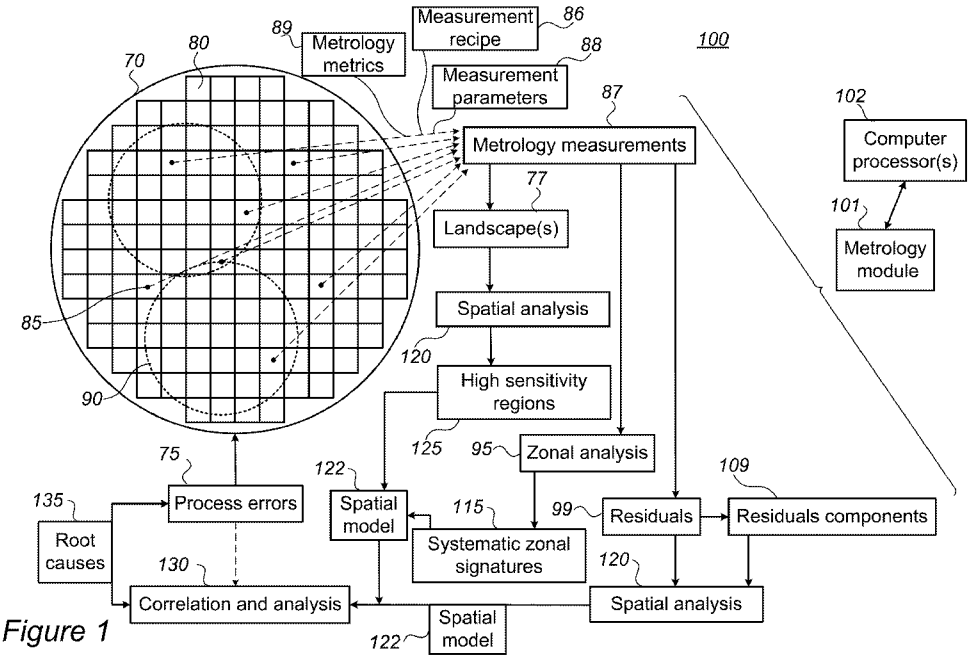

Figure 1

(57) Abstract: Systems, metrology modules and methods are provided, which identify, per wafer site, components of residuals from measurement of metrology metric(s), and optimize measurement parameters for each site, according to the identified residuals' components. Certain embodiments utilize metric landscapes to identify sensitive sites and/or to identify sites exhibiting highest accuracy, and corresponding metrics may be combined over the wafer to further enhance the metrology performance. Zonal analysis may be used to reduce the systematic errors, and disclosed per-site analysis may be used to further reduce the non-systematic error components, and relate the remaining residuals components to process variation over the wafer.

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PER-SITE RESIDUALS ANALYSIS FOR ACCURATE METROLOGY MEASUREMENTS

BACKGROUND OF THE INVENTION

1. TECHNICAL FIELD

[0001] The present invention relates to the field of metrology, and more particularly, to metrology recipe setup and measurement procedures.

2. DISCUSSION OF RELATED ART

[0002] Metrology measurements are carried out according to measurement recipes, which are optimized according to setup and measurement parameters. For example, U.S. Patent No. 7,570,796, which is incorporated herein by reference in its entirety, discloses various methods and systems for utilizing design data in combination with inspection data such as by comparing portions of design data in proximate positions to the defects in design data space and binning the defects in groups such that the portions of the design data proximate the positions of the defects in each of the groups are at least similar.

[0003] In another example, WIPO Publication No. 2018217232, which is incorporated herein by reference in its entirety, discloses metrology methods and modules which comprise carrying out recipe setup procedure(s) and/or metrology measurement(s) using zonal analysis with respect to respective setup parameter(s) and/or metrology metric(s). The zonal analysis comprises relating to spatially variable values of the setup parameter(s) and/or metrology metric(s) across one or more wafers in one or more lots. Wafer zones may be discrete or spatially continuous, and be used to weight one or more parameter(s) and/or metric(s) during any of the stages of the respective setup and measurement processes.

[0004] Analysis of metrology measurements across wafers or zones may be carried out with respect to one or more metrology landscape, that relates to an at least partially continuous dependency of at least one metrology metric (e.g., overlay for the overlay landscape) on at least one metrology measurement recipe parameter (e.g., illumination

parameters), which may be derived by simulation or in measurements. The derived dependency may be used to relate metrology measurements and process parameters in an analytical way or through simulation - as disclosed in U.S. Application Publication Nos. 2016/0313658 and 2018/0023950, incorporated herein by reference in their entirety.

SUMMARY OF THE INVENTION

[0005] The following is a simplified summary providing an initial understanding of the invention. The summary does not necessarily identify key elements nor limit the scope of the invention, but merely serves as an introduction to the following description.

[0006] One aspect of the present invention provides a method comprising: identifying, per wafer site, components of residuals from measurement of at least one metrology metric, and optimizing measurement parameters for each site, according to the identified residuals' components, wherein at least one of the identifying and the optimizing is carried out by at least one computer processor.

[0007] These, additional, and/or other aspects and/or advantages of the present invention are set forth in the detailed description which follows; possibly inferable from the detailed description; and/or learnable by practice of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] For a better understanding of embodiments of the invention and to show how the same may be carried into effect, reference will now be made, purely by way of example, to the accompanying drawings in which like numerals designate corresponding elements or sections throughout.

[0009] In the accompanying drawings:

[0010] **Figure 1** is a high-level schematic block diagram of systems, according to some embodiments of the invention.

[0011] **Figure 2** is a high-level flowchart illustrating methods, according to some embodiments of the invention.

[0012] **Figures 3A** and **3B** illustrate schematically inaccuracy landscape parts with respect to the wavelength as parameter, for different types of asymmetry, according to some embodiments of the invention.

[0013] **Figures 4** and **5** are high-level schematic illustrations of changes of an accuracy metric in two wafer locations, according to some embodiments of the invention.

[0014] **Figure 6** is a high-level schematic illustration of landscapes of an inaccuracy metric on different locations on wafer, and the corresponding division of the wafer to different zones according to the movement of the most accurate point, according to some embodiments of the invention.

[0015] **Figures 7A-7D** are high-level schematic illustrations the improved accuracy achieved by combining recipes over the wafer, according to some embodiments of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0016] In the following description, various aspects of the present invention are described. For purposes of explanation, specific configurations and details are set forth in order to provide a thorough understanding of the present invention. However, it will also be apparent to one skilled in the art that the present invention may be practiced without the specific details presented herein. Furthermore, well known features may have been omitted or simplified in order not to obscure the present invention. With specific reference to the drawings, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

[0017] Before at least one embodiment of the invention is explained in detail, it is to be understood that the invention is not limited in its application to the details of construction

and the arrangement of the components set forth in the following description or illustrated in the drawings. The invention is applicable to other embodiments that may be practiced or carried out in various ways as well as to combinations of the disclosed embodiments. Also, it is to be understood that the phraseology and terminology employed herein are for the purpose of description and should not be regarded as limiting.

[0018] Unless specifically stated otherwise, as apparent from the following discussions, it is appreciated that throughout the specification discussions utilizing terms such as "processing", "computing", "calculating", "determining", "enhancing", "deriving" or the like, refer to the action and/or processes of a computer or computing system, or similar electronic computing device, that manipulates and/or transforms data represented as physical, such as electronic, quantities within the computing system's registers and/or memories into other data similarly represented as physical quantities within the computing system's memories, registers or other such information storage, transmission or display devices. In certain embodiments, illumination technology may comprise, electromagnetic radiation in the visual range, ultraviolet or even shorter wave radiation such as x rays, and possibly even particle beams.

[0019] Embodiments of the present invention provide efficient and economical methods and mechanism for improving metrology performance and thereby provide improvements to the technological field of semiconductor production processes. Systems, metrology modules and methods are provided, which identify, per wafer site, components of residuals from measurement of metrology metric(s), and optimize measurement parameters for each site, according to the identified residuals' components. Certain embodiments utilize metric landscapes to identify sensitive sites and/or to identify sites exhibiting highest accuracy, and corresponding metrics may be combined over the wafer to further enhance the metrology performance. Zonal analysis may be used to reduce the systematic errors, and disclosed per-site analysis may be used to further reduce the non-systematic error components, and relate the remaining residuals components to process variation over the wafer.

[0020] In various embodiments, disclosed systems and methods improve the reported metrology performances by using a combination of different landscapes over the area of the wafer. Division to different zones or the selection of landscapes per site may be carried out by tracking metrics changes in value and behavior across the wafer. Any overlay metrology tool may be configured to carry out disclosed methods and incorporate disclosed metrology modules, to implement the disclosed methodology for breaking the residuals from the modeled overlay to their different contributions related to the quality of fitting, inaccuracy, process noise, etc.

[0021] **Figure 1** is a high-level schematic block diagram of systems **100**, according to some embodiments of the invention. **Figure 2** is a high-level flowchart illustrating methods **200**, according to some embodiments of the invention. The method stages may be carried out with respect to systems **100**, which may optionally be configured to implement method **200**. Method **200** may be at least partially implemented by at least one computer processor **102**, e.g., in a metrology module **101**. Certain embodiments comprise computer program products comprising a computer readable storage medium having computer readable program embodied therewith and configured to carry out the relevant stages of method **200**. Metrology module **101** may comprise, or be associated with one or more computer processor(s) **102** as part of metrology module **101** or associated therewith. Method **200** may comprise any of the following stages, irrespective of their order. Systems **100** and methods **200** are disclosed in the following and exemplified in **Figures 3-7D**.

[0022] Systems **100** and metrology modules **101** are configured to carry out metrology measurements **87**, at specified measurement parameters **88** (e.g., illumination parameters, tool settings, optical measurement parameters etc.) of respective measurement recipe **86**, of multiple targets at various sites **85** in a plurality of fields **80** of one or more wafer **70**.

[0023] Metrology modules **101** may be configured to identify, per wafer site **85**, components **109** of residuals **99** from measurement of at least one metrology metric **89**, and to optimize measurement parameters **88** for each site **85**, according to the identified

residuals' components **109**. Correspondingly, method **200** may comprise identifying, per wafer site, components of residuals from measurement of at least one metrology metric (stage **210**), and optimizing measurement parameters for each site, according to the identified residuals' components (stage **220**), wherein identifying **210** and/or optimizing **220** may be carried out by computer processor(s) **102**. For example, in certain embodiments, identifying **210** of the residuals' components may be carried out by principal component analysis (PCA) or by equivalent methods.

[0024] In certain embodiments, metrology module **101** may be further configured to identify components **109** of residuals **99** by comparing at least one metrology landscape **77** for wafer sites **85**, wherein metrology landscape(s) **77** comprises at least partially continuous dependency(ies) of at least one metrology metric **89** on at least one metrology measurement recipe parameter **88**. Method **200** may correspondingly comprise identifying the components of the residuals by comparing at least one metrology landscape for the wafer sites (stage **240**).

[0025] Landscapes **77**, as taught e.g., by U.S. Application Publication Nos. 2016/0313658 and 2018/0023950, incorporated herein by reference in their entirety, provide discrete or at least party continuously relations between metrology metric(s) **89** (e.g., measurability, quality, accuracy metrics) and corresponding measurement parameter(s) **88**; and can be used to detect, characterize and handle various features and errors in the production process.

[0026] For example, **Figures 3A** and **3B** illustrate schematically inaccuracy landscape parts with respect to the wavelength as parameter, for different types of asymmetry, according to some embodiments of the invention. **Figure 3A** illustrates schematically different inaccuracy intensities and **Figure 3B** illustrates schematically different inaccuracy orientations and corresponding sign. **Figures 3A** and **3B** schematically illustrate resonant regions **125** in landscapes **77** that are extremely sensitive to different kinds of process variations over wafer **70**, illustrated schematically in **Figures 3A** and **3B**.

Such resonance regions **125** may be utilized to relate the metrology parameters to the respective process variation, e.g., in spatial model **122**, and thereby to reduce the accompanying inaccuracy. For example, root causes **135** for the process variation may be identified, e.g., as specific deviations in any of the processes used to produce the wafer, such as scanner aberrations, process noise, chemical mechanical processing (CMP) effects, etching inaccuracies, and so forth. It is further noted that process variation changes across wafer **70** in type and in strength, and that different overlay metrology metrics **89** may be used to track the process variation within wafers **70** and/or from one wafer **70** to another wafer **70**, identifying signature(s) of the related process variation to analyze and derive root causes **135**, which may then be corrected. Method **200** may correspondingly comprise identifying root causes for the residuals based on the spatial relation (stage **246**).

[0027] In certain embodiments, metrology module **101** may be further configured to carry out identifying **210** and optimizing **220** at wafer sites **85** that exhibit high landscape sensitivity, possibly to relate changes in landscape(s) **77** spatially with respect to wafer sites **85**, and optionally carry out optimization **220** with respect to the derived spatial relation. Method **200** may further comprise carrying out the identifying and the optimizing at wafer sites that exhibit high landscape sensitivity (stage **242**), possibly relating changes in the landscape spatially with respect to the wafer sites and optionally carrying out the optimization with respect to the spatial relation (stage **244**).

[0028] In certain embodiments, metrology module **101** may be configured to relate changes in components **109** of residuals **99** spatially with respect to wafer sites **85**, and carry out optimization **220** with respect to the spatial relation. Method **200** may further comprise relating changes in the components of the residuals spatially with respect to the wafer sites, and carrying out the optimization with respect to the spatial relation (stage **250**). For example, the spatial relation may be at least partly continuous over wafer **70**.

[0029] As metrology measurements **87** (e.g., the overlay error) are related to target asymmetries, the measurement results are influenced by the distribution of process variation (e.g., structure asymmetries, SWA – side wall angles - as illustrated in **Figures**

3A and **3B**) over wafer **70**. Advantageously, spatial correlation and corresponding correction disclosed herein may therefore enhance measurement accuracy, enable tracking the accuracy and provides robust metrology (e.g., overlay) measurements **87** using different overlay metrics **89**. In various embodiments, disclosed systems **100** and methods **200** increase the accuracy and robustness of overlay metrology significantly, significantly reduce the residual part of the metrology measurement model and/or provide breakdown schemes for the specific and different contributions to residual **99** by different process factors or errors **75**, improving the extraction of correctable terms.

[0030] Spatial analysis **120** of measurements **87** may be applied to any of the distribution of sites **85**, zones **90** and/or landscape(s) **77** and their characteristics (e.g., transition points of regions, sig, slopes, etc.) and may be configured to yield a spatial model **122** of wafer **70** with respect to measurement characteristics such as used recipes **86**, sensitivities to measurement parameters, process variation and errors **75** etc.

[0031] Certain embodiments comprise refining and/or utilizing the zonal analysis disclosed in WIPO Publication No. 2018217232, which is incorporated herein by reference in its entirety. As illustrated schematically in **Figure 1**, zones **90** may comprise a relation between spatially variable values of the setup parameter(s) **88** and/or metrology metric(s) **89** across one or more wafers **70** in one or more lots. Wafer zones **90** may be discrete or spatially continuous.

[0032] Certain embodiments comprise metrology module(s) **101** further configured to remove systematic zonal signatures **115** from measurement(s) **87** to derive residuals **99**, prior to identifying **210** and optimizing **220**. Methods **200** may comprise removing systematic zonal signatures from the measurement to derive the residuals, prior to the identifying and the optimizing (stage **230**).

[0033] **Figures 4** and **5** are high-level schematic illustrations of changes of an accuracy metric in two wafer locations **85**, according to some embodiments of the invention. Landscapes **77** of accuracy metric **89** are illustrated in **Figure 4** for two different locations

85, located at different zones **90** (illustrated schematically, in a non-limiting manner with respect to the shape, size or other parameters of zones **90** and with respect to the relative positions of sites **85** within zones **90**).

[0034] In certain embodiments, systems **100** and methods **200** may be configured to measure wafers **70** by integrating the identification of different regions in landscapes **77** at sites **85** (e.g., resonance regions and regions with low sensitivity) and the spatial changes in landscape **77** across sites **85** on wafer **70**. The integration of landscape information and the spatial variability of the landscape may be used to derive a hybrid measurement recipe which utilizes selected landscape regions at corresponding selected regions of wafer, to minimize inaccuracy and moreover suggest root cause analysis of the process variation.

[0035] In certain embodiments, systems **100** and methods **200** may be configured to derive connections between different process variation factors (and/or process errors **75**) and different zones **90**, and refine the metrology results accordingly.

[0036] In certain embodiments, systems **100** and methods **200** may be configured to identify different process errors **75** relating to different zones **90**, e.g., structures in one zone **90** may exhibit top tilt while structures in another zone **90** may exhibit SWA, with the change of the asymmetric variation originating in the physical target. Zonal analysis **95** may be configured to detect the change point (or boundary **92**, which may comprise point(s), lines(s) or even area(s) between zones **90**) of the explored metric, and set the measurement setup to the optimal per process variation. For example, systems **100** and methods **200** may be configured to carry out the identifying and the optimizing at wafer sites located at zonal boundaries **92**, illustrated schematically in **Figure 4** in a non-limiting manner, as boundaries **92** may have any shape and may be fuzzy, covering certain area(s) of wafer **70** between zones **90**.

[0037] As illustrated in **Figure 5** schematically, metric value(s) **87** for specified recipes may have specified distributions of wafer **70**, which may be utilized to derive landscape

characteristics **77A** such as transition points or regions **77B**, in the illustrated case non-differential point **77B**, having an undefined derivative due to the change in slope at the specified distance (indicated as "threshold") from the center of wafer **70**. It is noted that schematically illustrated metric value(s) **87** may represent multiple types of metrics **89** or their combinations, and the illustration is simplified to enhance the clarity of the explanation. It is noted that in terms of zonal analysis, zone **90** may be defined as being within the threshold radius and another zone may be defined as being outside the threshold radius, the zones being separated by boundary **92** at the threshold radius. It is further noted that the described analysis corresponds to one measurement recipe, and may vary between recipes, providing additional data that can be derived by combination of identified thresholds over changing recipes and corresponding relations between changes in measurement parameters **88** and changes in thresholds and boundaries **92**.

[0038] In certain embodiments, systems **100** and methods **200** may be configured to identify different metric parameters related to the same process variation, relating to different zones **90** or boundaries with respect to the same process variation. Zonal analysis **95** may be configured to detect the change point(s) (or boundary **92**, which may comprise point(s), lines(s) or even area(s) between zones **90**) of the explored metric, and set the measurement setup to the optimal per process variation. For example, systems **100** and methods **200** may be configured to carry out the identifying and the optimizing at wafer sites located at zonal boundaries **92**, illustrated schematically in **Figure 5** in a non-limiting manner, as boundaries **92** may have any shape and may be fuzzy, covering certain area(s) of wafer **70** between zones **90**. For example, changes in the values of process variation **75** may yield sites **85** and/or zones **90** as parts of wafer **70** which are highly sensitive to the process variation while other parts may be more mildly sensitive, or not sensitive at all – using the same recipe.

[0039] Systems **100** and methods **200** may be configured to use different recipes **86** to different parts of wafer **90**, such as zones **90**, groups of sites **85** and/or zone boundary regions **92**, according to the corresponding most accurate recipe **86** in each part. It is noted that the examples illustrated in **Figures 4** and **5** are simplified, and that zones **90**

corresponding to the accuracy metric signatures may have any shape, e.g., not necessarily circular and/or central, and may have any shape on wafer **70**. The number of zones **90** is also not limited, e.g., wafer **70** may be divided to multiple zones **90**, each allocated a different recipe for metrology measurements. Zone arrangement and measurement recipes may be validated during operation, e.g., by calculating corresponding accuracy metrics **89** on new wafers **70** and comparing calculation models **122** for new wafers **70**.

[0040] Certain embodiments comprise metrology module(s) **101** further configured to use zonal analysis **95** that relates spatially variable values of at least one setup parameter to wafer location, with respect to at least one setup metrology metric **89** that is different from at least one metrology metric **89** that is used to carry out identifying **210** and optimizing **220**. Methods **200** may comprise using zonal analysis that relates spatially variable values of at least one setup parameter to wafer location, with respect to at least one setup metrology metric that is different from the at least one metrology metric that is used to carry out the identifying and the optimizing (stage **260**). In certain embodiments, zonal analysis **95** may be at least partly discrete with respect to wafer sites **85**. In certain embodiments, zonal analysis **95** may be at least partly continuous with respect to wafer sites **85**.

[0041] **Figure 6** is a high-level schematic illustration of landscapes **77** of an inaccuracy metric **89** on different locations **85** on wafer **70**, and the corresponding division of wafer **70** to different zones **90** according to the movement of the most accurate point, according to some embodiments of the invention. The illustrated example is based on ca. **200** site measurements on IBO (Image Based Overlay) targets. Illustrated landscapes **77** include three types of landscapes **77C**, **77D**, **77E** of the measured example, with corresponding three most accurate points **78A**, **78B**, **78C** on the respective landscapes, indicating measurement parameters **88** (in the illustrated case – the illumination wavelength) which minimize inaccuracy metric **89**. Corresponding sites **85** on wafer **70** are indicated according to measurement parameter **88** of respective most accurate point **78A**, **78B**, **78C**, yielding corresponding zones **90A**, **90B**, **90C**, each including sites **85** in which the most accurate points are at corresponding wavelengths. It is noted that shift of the most accurate point

with respect to the measurement parameter across the wafer is distinctly observable. The illustrated division of wafer **70** into zones **90** is schematic and served as a non-limiting example. It is noted that multiple number of zones **90** may be defined with respect to multiple measurement parameters **88** and/or multiple metrology metrics **89**, and that zones **90** may have spatially discrete and/or continuous parts on wafer **70**. It is also noted that in certain embodiments, zones **90** over wafer **70** may be selected with respect to one or more certain metrics, while measurement recipe(s) **86** may be selected according to different one or more metrics **89**.

[0042] **Figures 7A-7D** are high-level schematic illustrations the improved accuracy achieved by combining recipes **86** over wafer **70**, according to some embodiments of the invention. The illustrated example is based on ca. 300 site measurements on IBO targets. **Figure 7A** illustrates measurements using one Recipe A **86A**, which provides low inaccuracy at the central part of wafer **70** and high inaccuracy at two side regions of wafer **70**. **Figure 7B** illustrates allocation of alternative Recipe **86B** to the side regions of wafer **70**, Recipe B **86B** having lower inaccuracy at these specific regions than Recipe A **86A**. **Figure 7C** illustrates a typical prior art solution of correction of the measurements at the level of the calculation model **88** and **Figure 7D** compares the performance of disclosed combined recipes with the prior art correction and the combination of accuracy provided by the Recipes A and B, split according to model terms, to indicate the over-measurement in prior art methods that results in overall higher inaccuracy compared to disclosed combined recipes.

[0043] Advantageously, combining a few recipes across wafers **70** provides selecting for each zone **90** and/or site **85** the best recipe that is suitable for it from physical considerations, and provides more accurate metrology values across wafer **70**.

[0044] Disclosed embodiments provide a methodology for reducing residuals **99** as well as for performing a breakdown of residuals components **109** for evaluating the real contribution of inaccuracies to residuals **99**. Advantageously, disclosed systems **100** and methods **200** considerably increase the overlay metrology ability to select accurate, robust

and well modeled overlay recipes as well as performing root cause analysis **130** of the wafer behavior in term of accuracy, process variation, model relevancy etc.

[0045] In certain embodiments, systems **100** and methods **200** may be configured to select measurement parameters **88** as a measurement recipe for sites **85** which do not present a clear zone signature, and/or at boundaries between zones **90** and/or in areas that are not allocated to specific zones **90**.

[0046] In certain embodiments, metrology module **101** may be further configured to analyze components **109** of residuals **99** with respect to associated process errors **75** and in relation to wafer site locations **85**. Methods **200** may be configured to analyze the components of the residuals with respect to associated process errors and in relation to wafer site locations (stage **270**).

[0047] Disclosed embodiments enable further analysis of residuals components **109**, e.g., spatial analysis **120**, to provide further correction and analysis **130** of process variation and errors **75**, beyond zonal analysis **95** and systematic zonal signatures **115**. The analysis of residuals components **109** may be carried out per site **85** and possibly used to allocated weights to measurements from different sites **85**. Advantageously, residuals components **109**, spatial analysis **120** and spatial model **122** provide information concerning non-systematic components of residuals **99**, enhancing the accuracy of measurements **87**. The identification of residuals components **109** may further be optimized per site **85**, e.g., with respect to multiple recipes and metrics **89** and/or multiple landscapes 77 at each site **85**.

[0048] It is noted that one of the most important indicators the fab is relying on for stability and accuracy evaluation of the selected recipe is residuals **99**, which express the difference between the modeled overlay, calculated by extracting the correctable term for the overlay correction and the real per-site overlay received from overlay metrology. It is assumed that a good fit of the model is also a good indication of the overlay metrology performance and accuracy. However, as understood by the inventors, the quality of fit is not necessarily

directly correlated to the real accuracy, and a well distributed process variation could be modelled with low residuals **99**, which may potentially lead to errors in the recipe selection.

[0049] Aspects of the present invention are described above with reference to flowchart illustrations and/or portion diagrams of methods, apparatus (systems) and computer program products according to embodiments of the invention. It will be understood that each portion of the flowchart illustrations and/or portion diagrams, and combinations of portions in the flowchart illustrations and/or portion diagrams, can be implemented by computer program instructions. These computer program instructions may be provided to a processor of a general-purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or portion diagram or portions thereof.

[0050] These computer program instructions may also be stored in a computer readable medium that can direct a computer, other programmable data processing apparatus, or other devices to function in a particular manner, such that the instructions stored in the computer readable medium produce an article of manufacture including instructions which implement the function/act specified in the flowchart and/or portion diagram or portions thereof.

[0051] The computer program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other devices to cause a series of operational steps to be performed on the computer, other programmable apparatus or other devices to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide processes for implementing the functions/acts specified in the flowchart and/or portion diagram or portions thereof.

[0052] The aforementioned flowchart and diagrams illustrate the architecture, functionality, and operation of possible implementations of systems, methods and computer program products according to various embodiments of the present invention. In this regard, each portion in the flowchart or portion diagrams may represent a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function(s). It should also be noted that, in some alternative implementations, the functions noted in the portion may occur out of the order noted in the figures. For example, two portions shown in succession may, in fact, be executed substantially concurrently, or the portions may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each portion of the portion diagrams and/or flowchart illustration, and combinations of portions in the portion diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts, or combinations of special purpose hardware and computer instructions.

[0053] In the above description, an embodiment is an example or implementation of the invention. The various appearances of "one embodiment", "an embodiment", "certain embodiments" or "some embodiments" do not necessarily all refer to the same embodiments. Although various features of the invention may be described in the context of a single embodiment, the features may also be provided separately or in any suitable combination. Conversely, although the invention may be described herein in the context of separate embodiments for clarity, the invention may also be implemented in a single embodiment. Certain embodiments of the invention may include features from different embodiments disclosed above, and certain embodiments may incorporate elements from other embodiments disclosed above. The disclosure of elements of the invention in the context of a specific embodiment is not to be taken as limiting their use in the specific embodiment alone. Furthermore, it is to be understood that the invention can be carried out or practiced in various ways and that the invention can be implemented in certain embodiments other than the ones outlined in the description above.

[0054] The invention is not limited to those diagrams or to the corresponding descriptions. For example, flow need not move through each illustrated box or state, or in exactly the same order as illustrated and described. Meanings of technical and scientific terms used herein are to be commonly understood as by one of ordinary skill in the art to which the invention belongs, unless otherwise defined. While the invention has been described with respect to a limited number of embodiments, these should not be construed as limitations on the scope of the invention, but rather as exemplifications of some of the preferred embodiments. Other possible variations, modifications, and applications are also within the scope of the invention. Accordingly, the scope of the invention should not be limited by what has thus far been described, but by the appended claims and their legal equivalents.

CLAIMS

What is claimed is:

1. A method comprising:

identifying, per wafer site, components of residuals from measurement of at least one metrology metric, and

optimizing measurement parameters for each site, according to the identified residuals' components,

wherein at least one of the identifying and the optimizing is carried out by at least one computer processor.

2. The method of claim 1, further comprising identifying the components of the residuals by comparing at least one metrology landscape for the wafer sites, wherein the metrology landscape comprises an at least partially continuous dependency of the at least one metrology metric on at least one metrology measurement recipe parameter.
3. The method of claim 2, further comprising carrying out the identifying and the optimizing at wafer sites that exhibit high landscape sensitivity.
4. The method of claim 2, further comprising relating changes in the landscape spatially with respect to the wafer sites, and carrying out the optimization with respect to the spatial relation.
5. The method of claim 4, further comprising identifying root causes for the residuals based on the spatial relation.
6. The method of any one of claims 2-5, wherein the identifying of the residuals' components is carried out by principal component analysis (PCA).
7. The method of any one of claims 1-6, further comprising removing systematic zonal signatures from the measurement to derive the residuals, prior to the identifying and the optimizing.
8. The method of claim 7, further comprising carrying out the identifying and the optimizing at wafer sites located at zonal boundaries.
9. The method of any one of claims 1-8, further comprising relating changes in the components of the residuals spatially with respect to the wafer sites, and carrying out the optimization with respect to the spatial relation.
10. The method of claim 9, wherein the spatial relation is continuous over the wafer.

11. The method of any one of claims 1-10, further comprising using zonal analysis that relates spatially variable values of at least one setup parameter to wafer location, with respect to at least one setup metrology metric that is different from the at least one metrology metric that is used to carry out the identifying and the optimizing.
12. The method of claim 11, wherein the zonal analysis is discrete with respect to the wafer sites.
13. The method of any one of claims 1-12, further comprising analyzing the components of the residuals with respect to associated process errors and in relation to wafer site locations.
14. A computer program product comprising a non-transitory computer readable storage medium having computer readable program embodied therewith, the computer readable program configured to carry out the method of any one of claims 1-13.
15. Metrology measurements derived from the method of any one of claims 1-13.
16. A metrology module configured to identify, per wafer site, components of residuals from measurement of at least one metrology metric, and to optimize measurement parameters for each site, according to the identified residuals' components.
17. The metrology module of claim 16, further configured to identify the components of the residuals by comparing at least one metrology landscape for the wafer sites, wherein the metrology landscape comprises an at least partially continuous dependency of the at least one metrology metric on at least one metrology measurement recipe parameter.
18. The metrology module of claim 17, further configured to carry out the identifying and the optimizing at wafer sites that exhibit high landscape sensitivity.
19. The metrology module of claim 17, further configured to relate changes in the landscape spatially with respect to the wafer sites, and to carry out the optimization with respect to the spatial relation.
20. The metrology module of claim 19, further configured to identify root causes for the residuals based on the spatial relation.
21. The metrology module of any one of claims 16-20, wherein the identifying of the residuals' components is carried out by principal component analysis (PCA).

22. The metrology module of any one of claims 16-21, further configured to remove systematic zonal signatures from the measurement to derive the residuals, prior to the identifying and the optimizing.
23. The metrology module of claim 22, further configured to carry out the identifying and the optimizing at wafer sites located at zonal boundaries.
24. The metrology module of any one of claims 16-23, further configured to relate changes in the components of the residuals spatially with respect to the wafer sites, and carry out the optimization with respect to the spatial relation.
25. The metrology module of any one of claims 16-24, further configured to use zonal analysis that relates spatially variable values of at least one setup parameter to wafer location, with respect to at least one setup metrology metric that is different from the at least one metrology metric that is used to carry out the identifying and the optimizing.
26. The metrology module of any one of claims 16-25, further configured to analyze the components of the residuals with respect to associated process errors and in relation to wafer site locations.

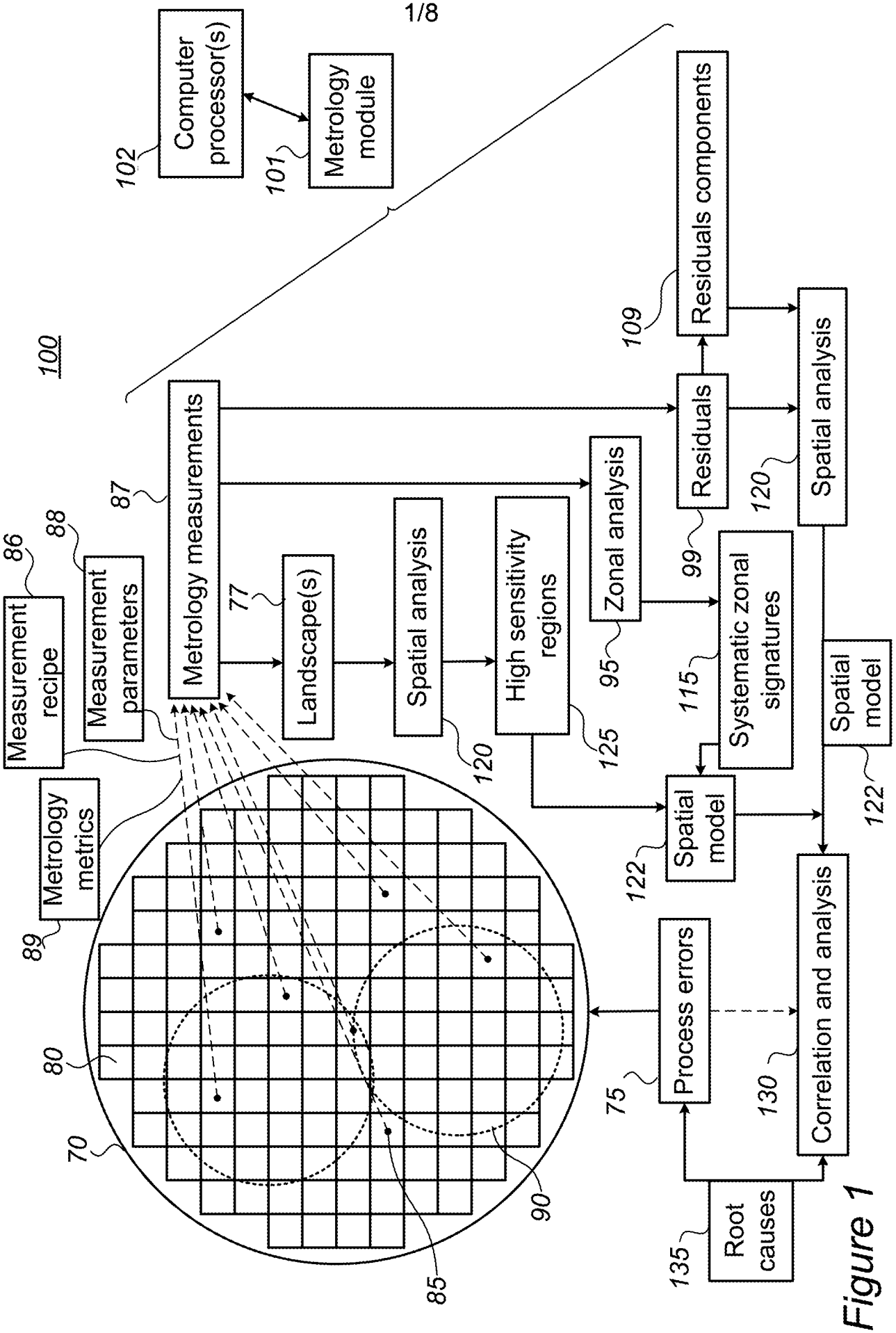
100
Computer processor(s)
102
Metrology module
101
Metrology measurements
87
Measurement recipe
86
Measurement parameters
88
Metrology metrics
89
Landscape(s)
77
Spatial analysis
120
High sensitivity regions
125
Zonal analysis
95
Residuals
99
Residuals components
109
Systematic zonal signatures
115
Spatial analysis
120
Spatial model
122
Spatial model
122
Process errors
75
Correlation and analysis
130
Root causes
135
70
80
85
90

Figure 1

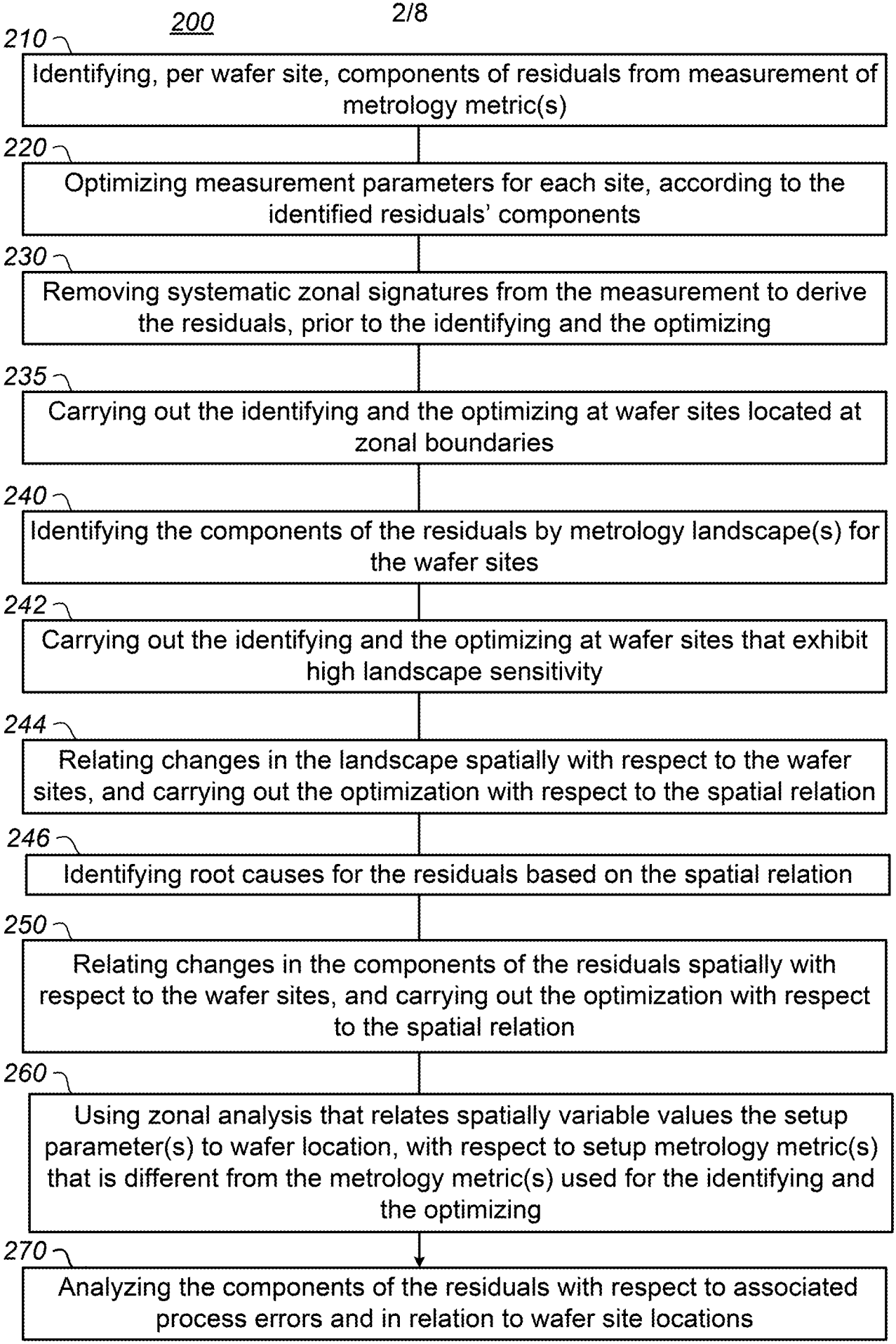
200
210
Identifying, per wafer site, components of residuals from measurement of metrology metric(s)
220
Optimizing measurement parameters for each site, according to the identified residuals' components
230
Removing systematic zonal signatures from the measurement to derive the residuals, prior to the identifying and the optimizing
235
Carrying out the identifying and the optimizing at wafer sites located at zonal boundaries
240
Identifying the components of the residuals by metrology landscape(s) for the wafer sites
242
Carrying out the identifying and the optimizing at wafer sites that exhibit high landscape sensitivity
244
Relating changes in the landscape spatially with respect to the wafer sites, and carrying out the optimization with respect to the spatial relation
246
Identifying root causes for the residuals based on the spatial relation
250
Relating changes in the components of the residuals spatially with respect to the wafer sites, and carrying out the optimization with respect to the spatial relation
260
Using zonal analysis that relates spatially variable values the setup parameter(s) to wafer location, with respect to setup metrology metric(s) that is different from the metrology metric(s) used for the identifying and the optimizing
270
Analyzing the components of the residuals with respect to associated process errors and in relation to wafer site locations

Figure 2

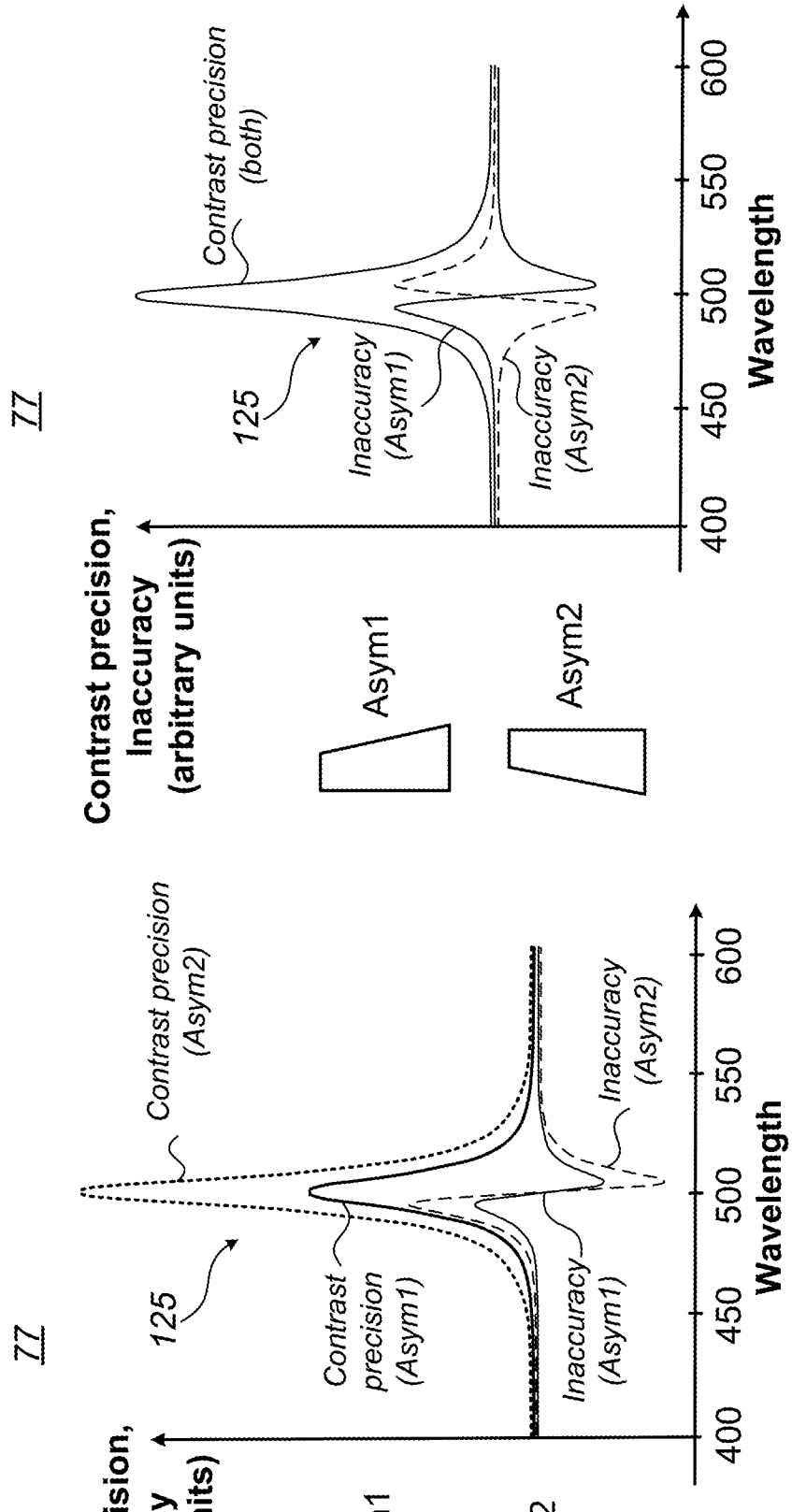

Figure 3A

Figure 3B

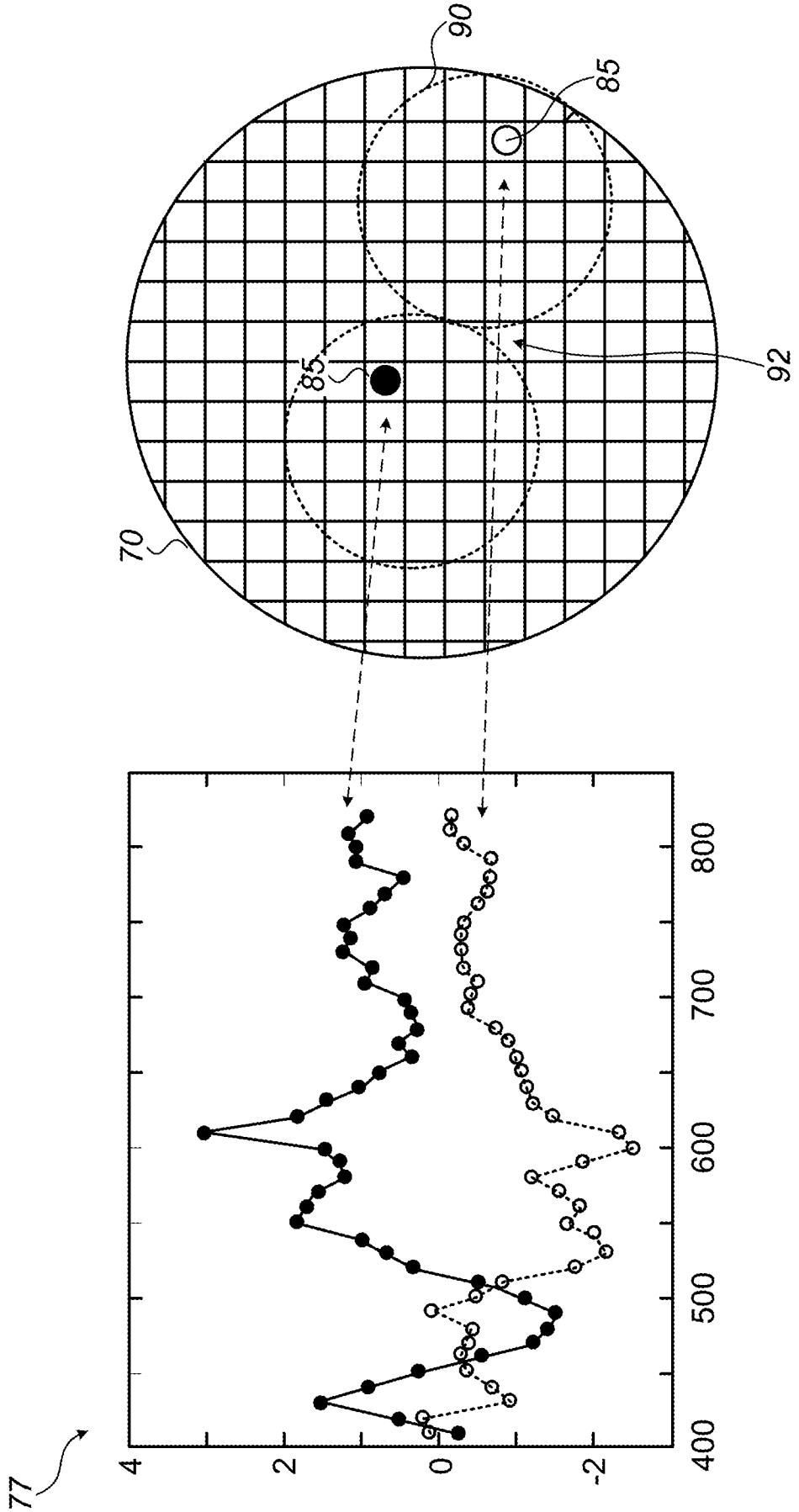

Figure 4

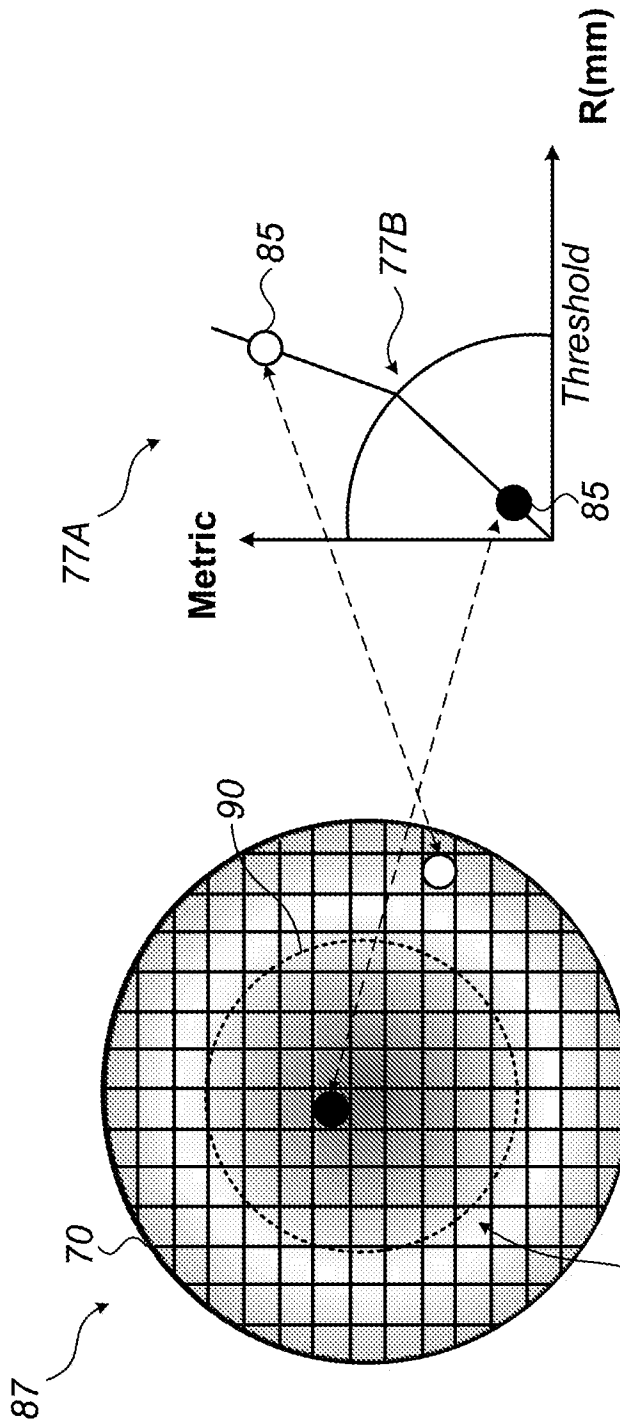

Figure 5

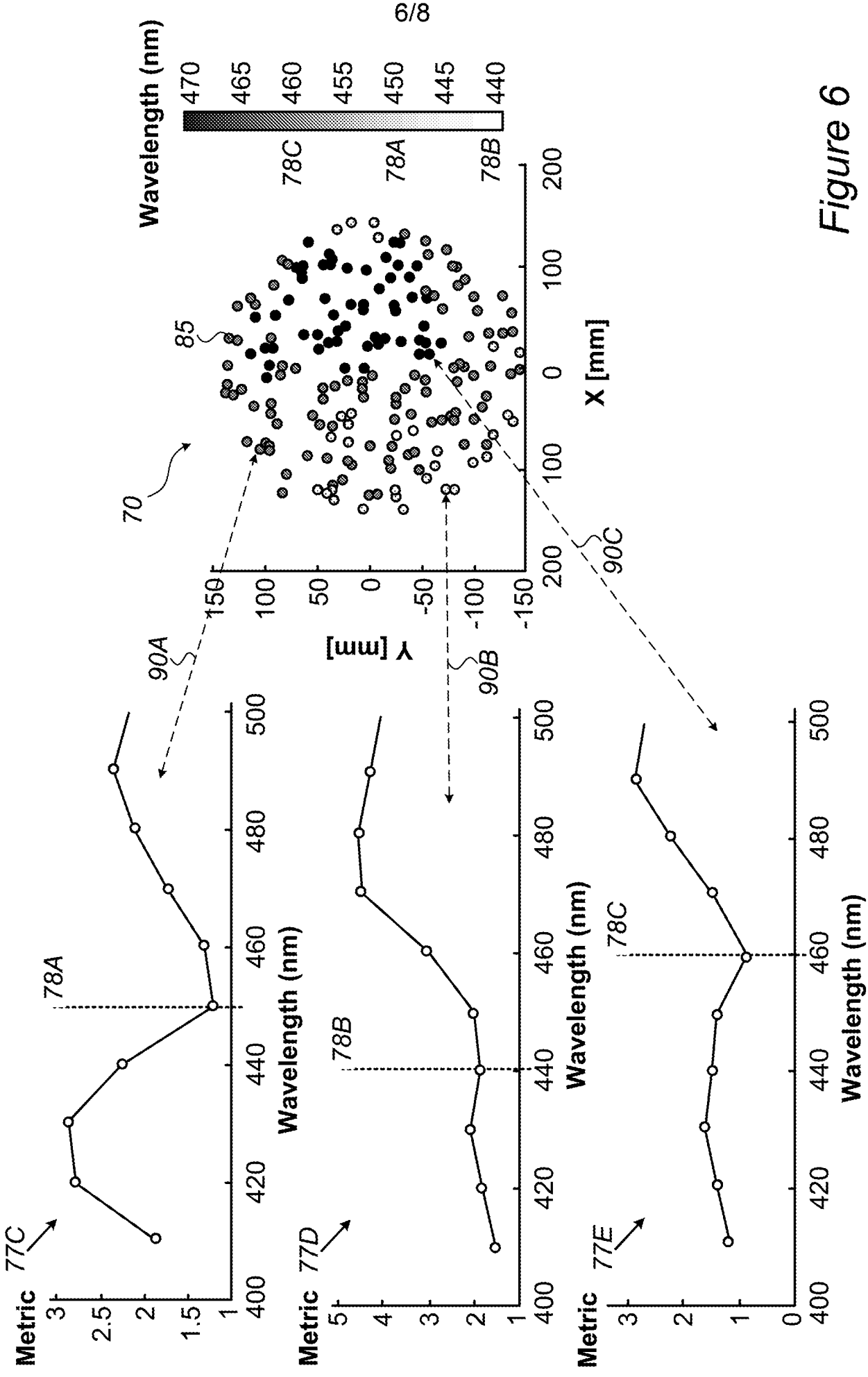
Wavelength (nm)
470
465
460
455
450
445
440
78C
78A
78B
85
70
Y [mm]
X [mm]
90A
90B
90C
77C
77D
77E
Metric
Wavelength (nm)
78A
78B
78C

Figure 6

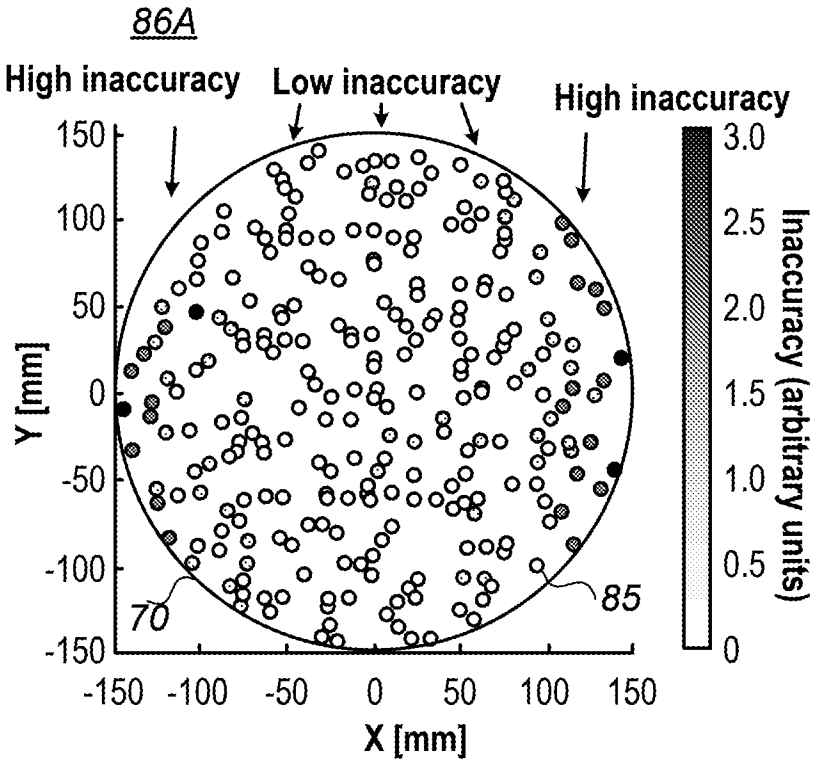

Figure 7A

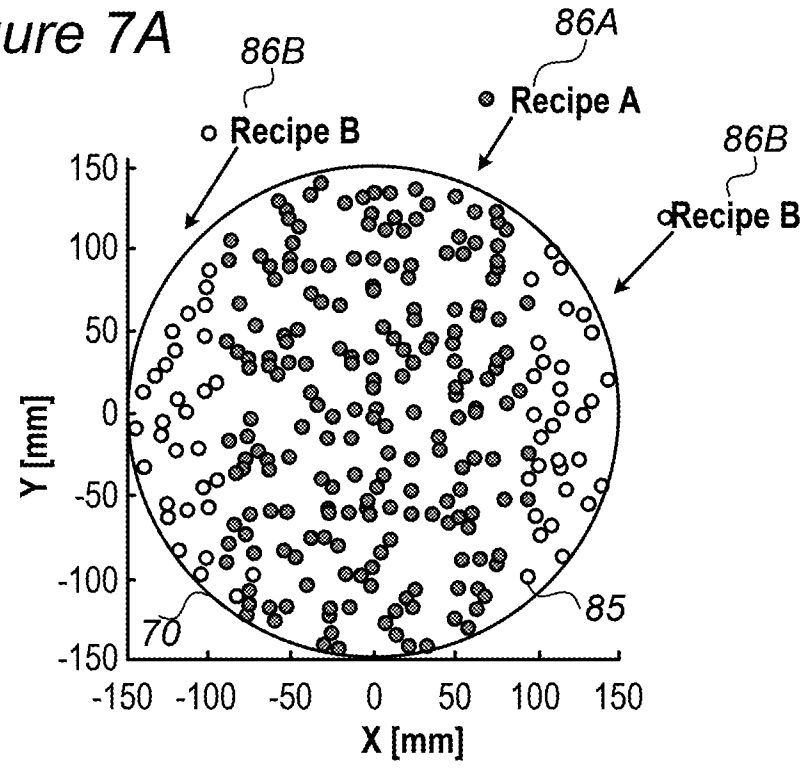

Figure 7B

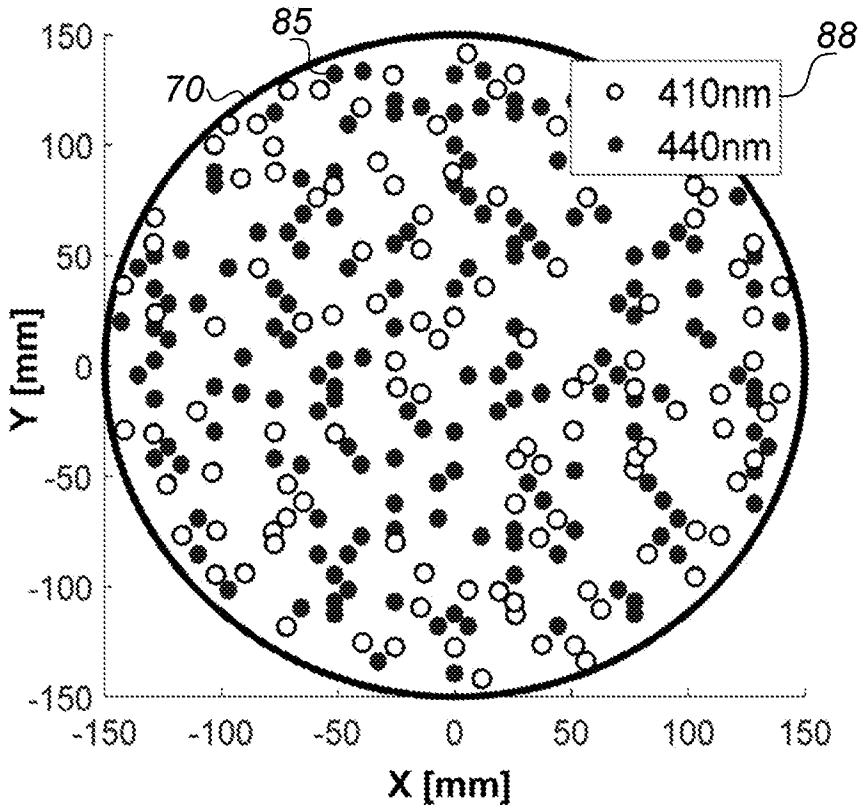

Figure 7C – Prior art

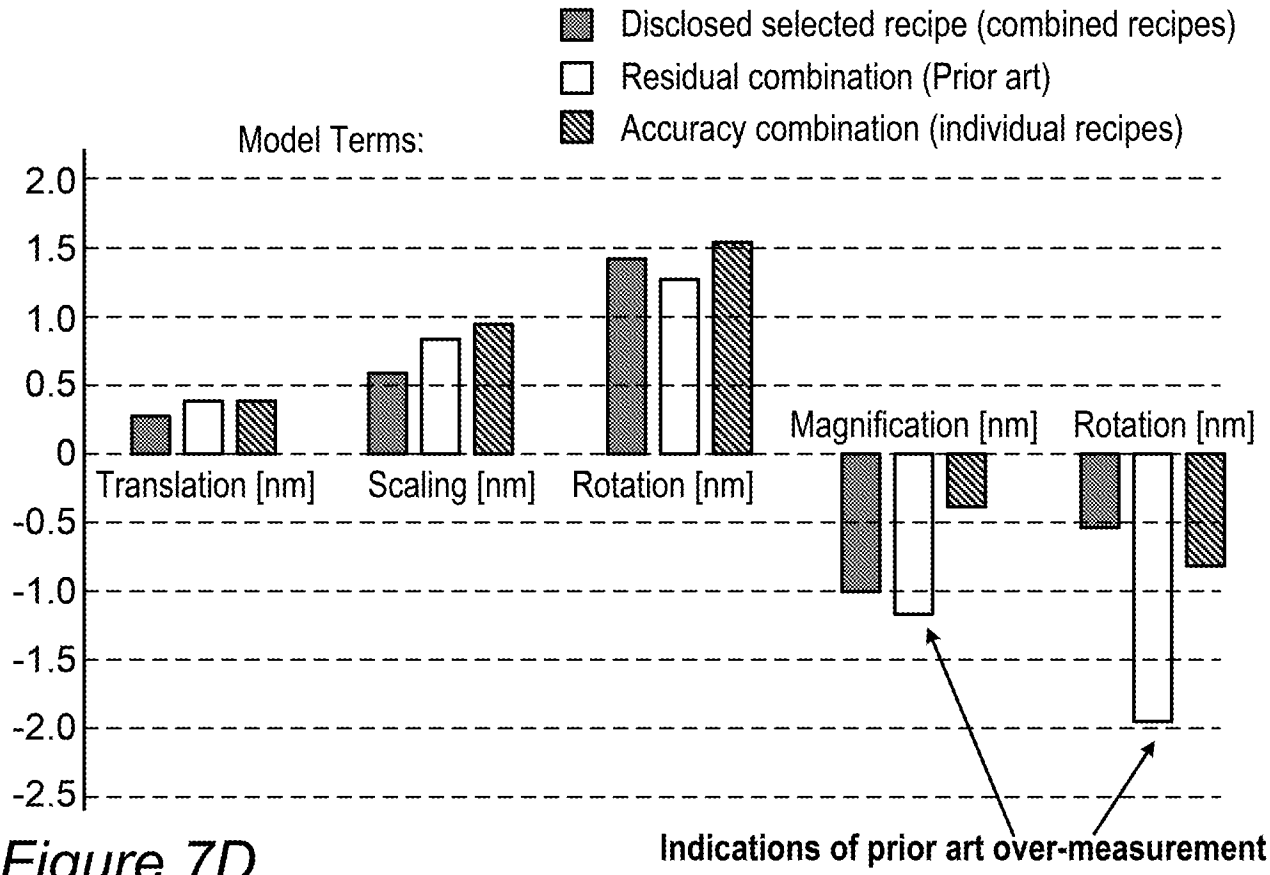

Figure 7D

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2019/053715

A. CLASSIFICATION OF SUBJECT MATTER

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)
H01L 21/66; G01B 11/00; G01B 11/14; G01N 21/00; G03F 7/20; G06F 7/48

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: wafer, site, residuals, metrology, measurement

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014-0273291 A1 (TAIWAN SEMICONDUCTOR MANUFACTURING CO., LTD.) 18 September 2014 Paragraph 24; claims 1, 19; and figure 4.	1,16
Y		2-6,17-21
Y	US 2018-0047646 A1 (KLA-TENCOR CORPORATION) 15 February 2018 Paragraphs 55-124; claim 4; and figures 3-4.	2-6,17-21
X	US 2011-0170091 A1 (ELLIS CHANG et al.) 14 July 2011 Paragraphs 37-38, 53-54; claim 1; and figures 1-3.	1,16
A	US 2018-0252514 A1 (KLA-TENCOR CORPORATION) 06 September 2018 The entire document.	1-6,16-21
A	US 2017-0160073 A1 (ASML NETHERLANDS B.V.) 08 June 2017 The entire document.	1-6,16-21

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"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	Date of mailing of the international search report
13 January 2020 (13.01.2020)	**13 January 2020 (13.01.2020)**

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea
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Telephone No. +82-42-481-3463

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2019/053715

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 8,10,12,23
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

Claims 8, 10, 12 and 23 are regarded to be unclear because they refer to claims 7, 9, 11 and 22 respectively, which do not comply with PCT Rule 6.4(a).

3. ☒ Claims Nos.: 7,9,11,13-15,22,24-26
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required addtional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of any additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2019/053715

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2014-0273291 A1	18/09/2014	KR 10-1506397 B1	26/03/2015
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		TW 201203416 A	16/01/2012
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		US 9170209 B1	27/10/2015
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		WO 2018-160779 A1	07/09/2018
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		KR 10-2017-0018097 A	15/02/2017
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		US 10317191 B2	11/06/2019
		US 2014-0354969 A1	04/12/2014
		US 9594029 B2	14/03/2017
		WO 2013-092106 A1	27/06/2013