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(54) **REGISTRATION BETWEEN AN INSPECTION IMAGE AND A DESIGN IMAGE**

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(52) **U.S. Cl.**

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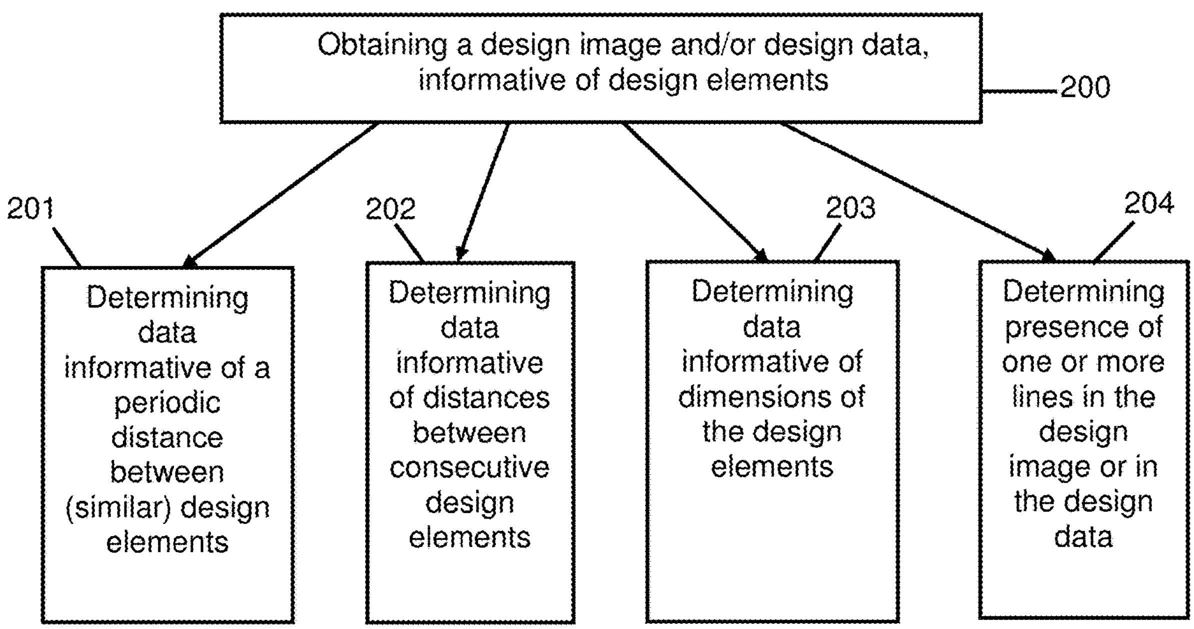
(57) **ABSTRACT**

There are provided systems and methods comprising obtaining an inspection image of a semiconductor specimen, and a design image, wherein the design image is informative of design elements, determining data D_{pitch} informative of a periodic distance between design elements of the design image, which are associated with a shape meeting a similarity criterion, and using the data D_{pitch} to obtain registration data between the design image and the inspection image.



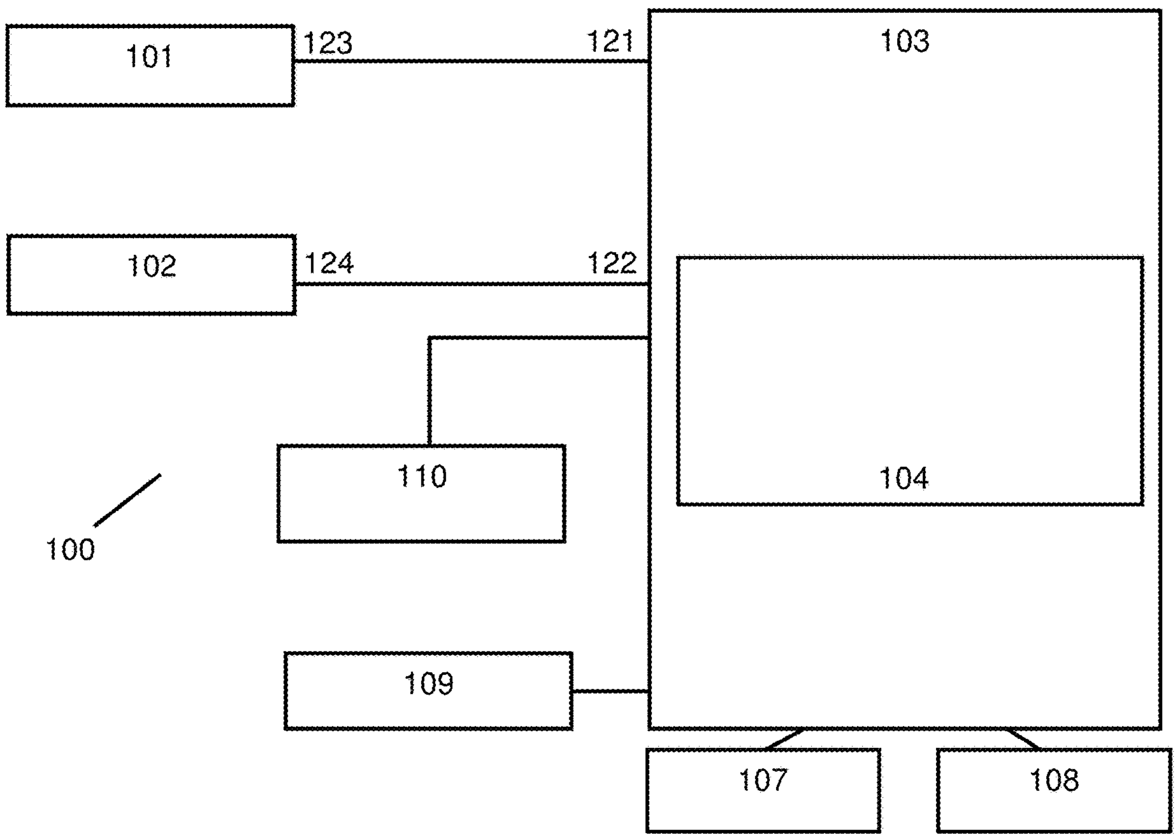


FIG. 1

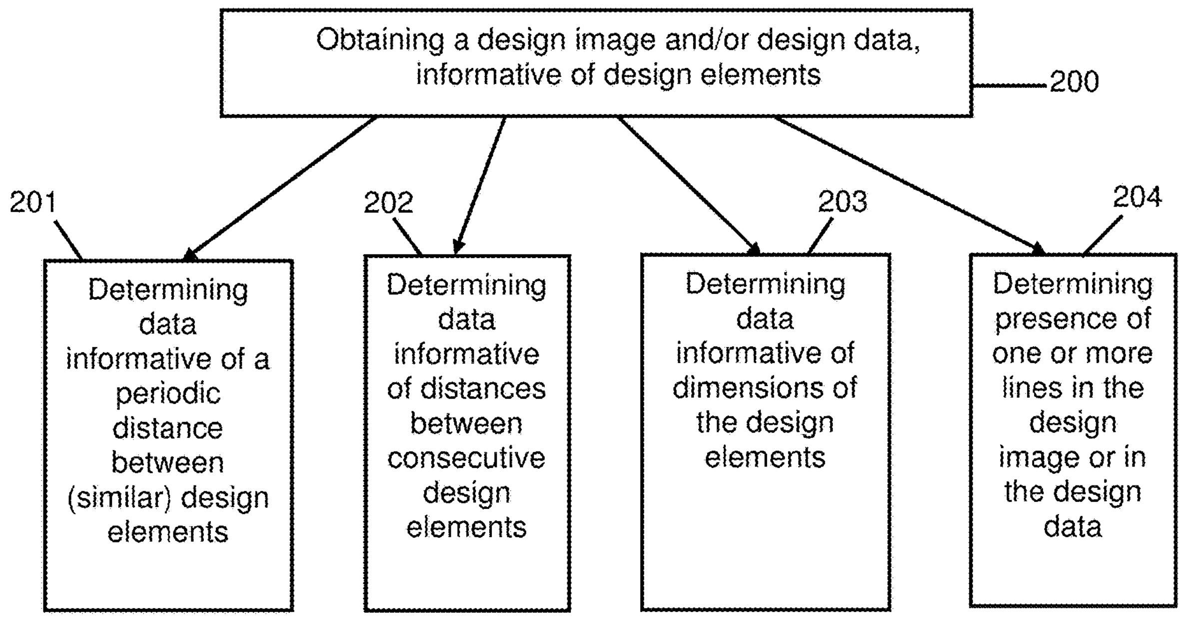
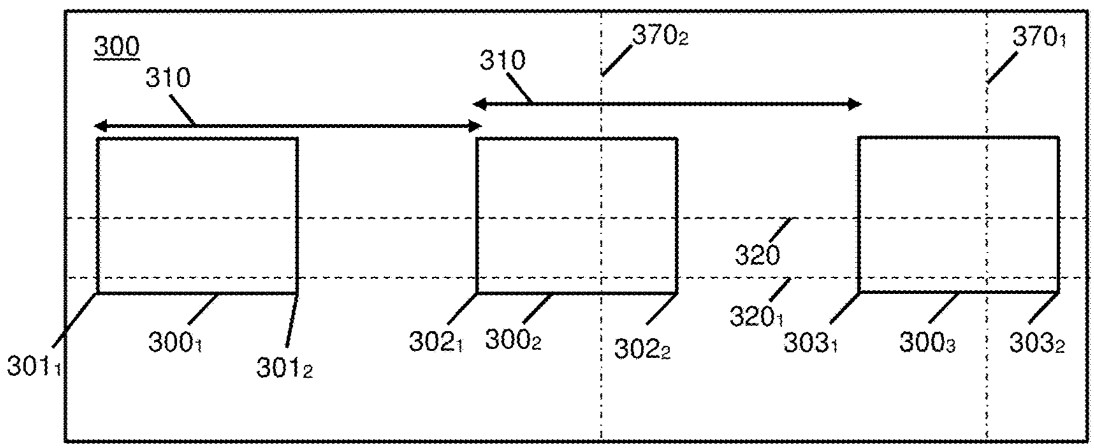

Obtaining a design image and/or design data, informative of design elements
200
201
Determining data informative of a periodic distance between (similar) design elements
202
Determining data informative of distances between consecutive design elements
203
Determining data informative of dimensions of the design elements
204
Determining presence of one or more lines in the design image or in the design data

FIG. 2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310
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370₂
370₁
320
320₁
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303₁
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303₂

FIG. 3A

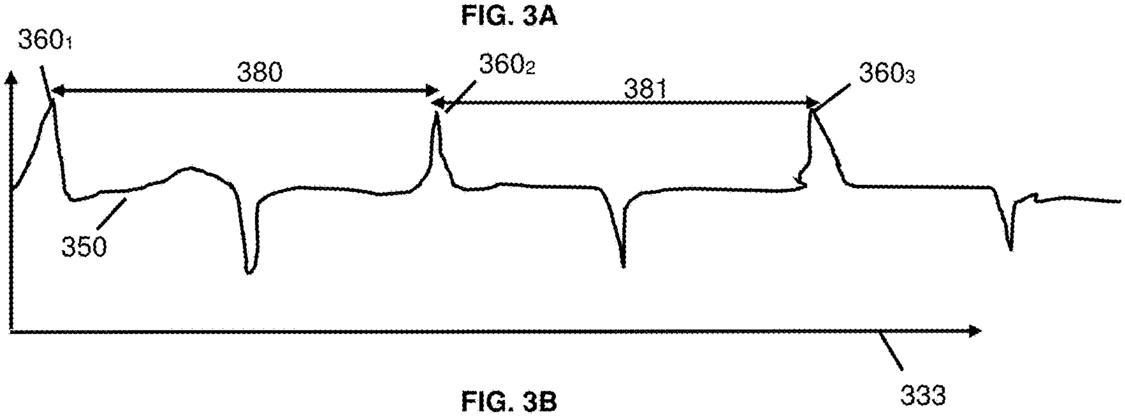
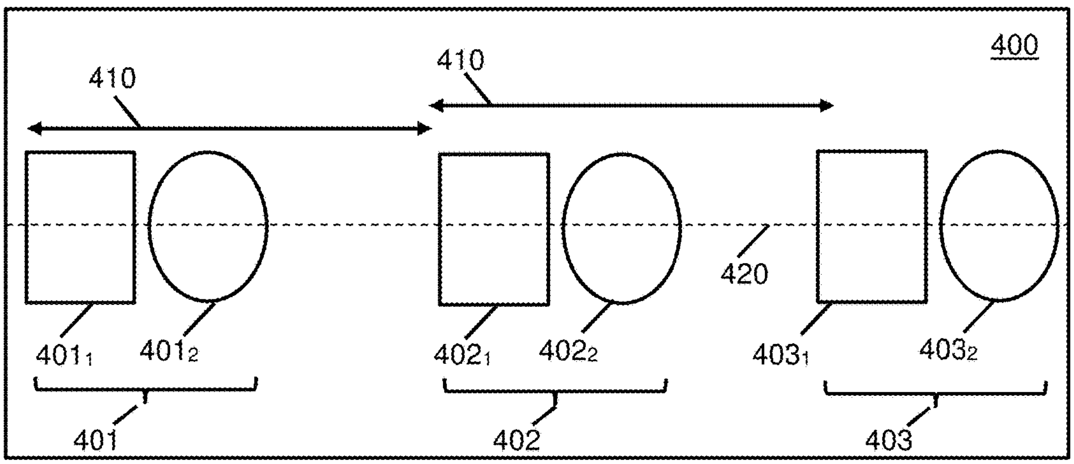

360₁
380
360₂
381
360₃
350
333

FIG. 3B


400
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401_1
401_2
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403_1
403_2
401
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403

FIG. 4A

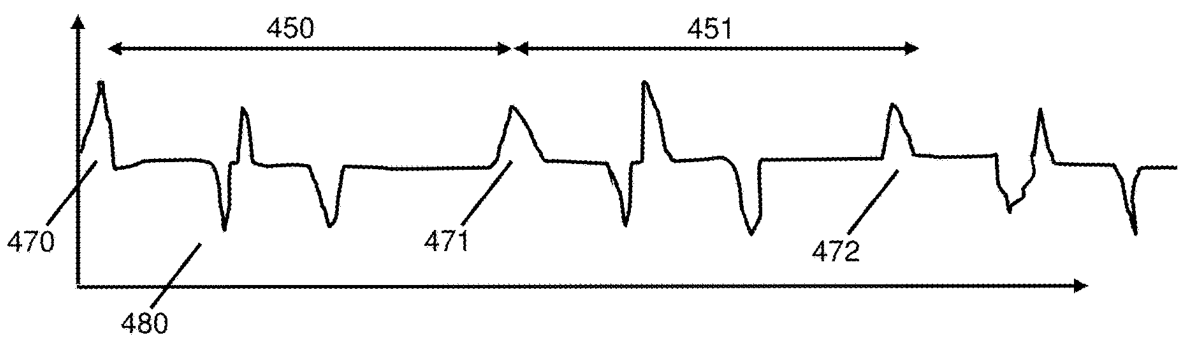
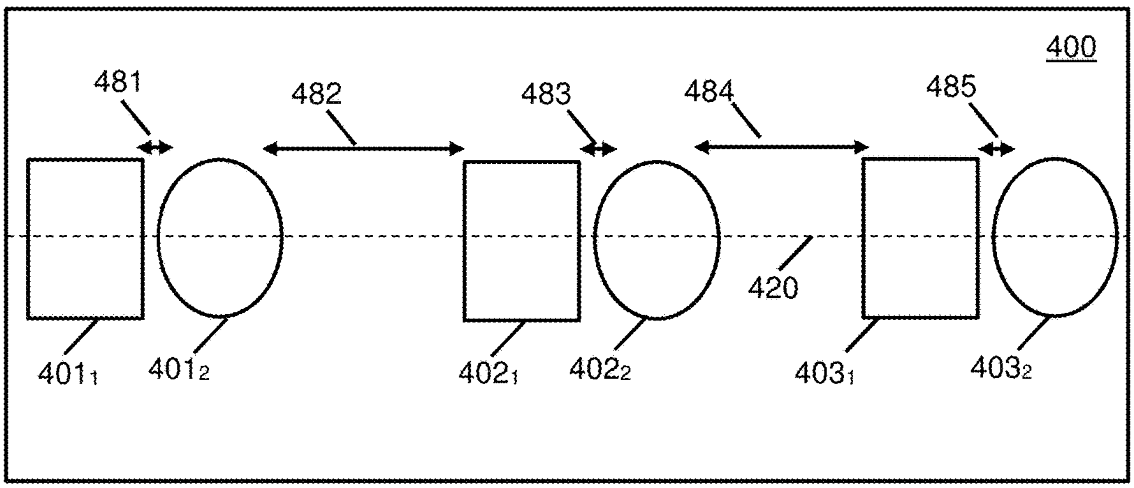

450
451
470
471
472
480

FIG. 4B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481
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483
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401₁
401₂
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403₂

FIG. 4C

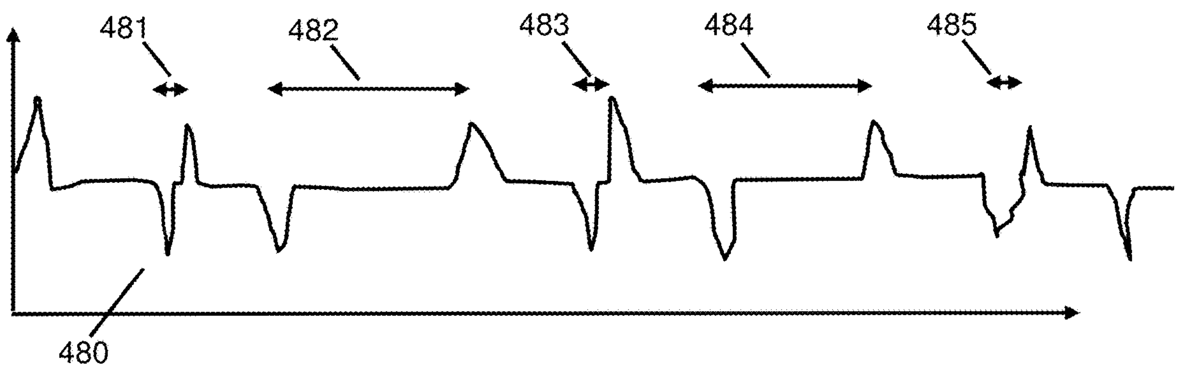
481
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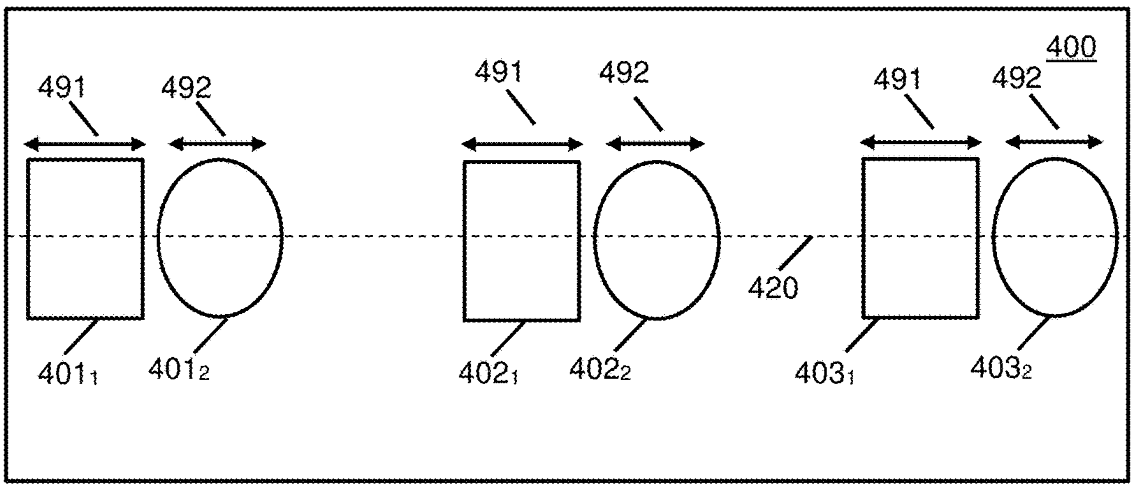
FIG. 4D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491
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401_1
401_2
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402_2
403_1
403_2

FIG. 4E

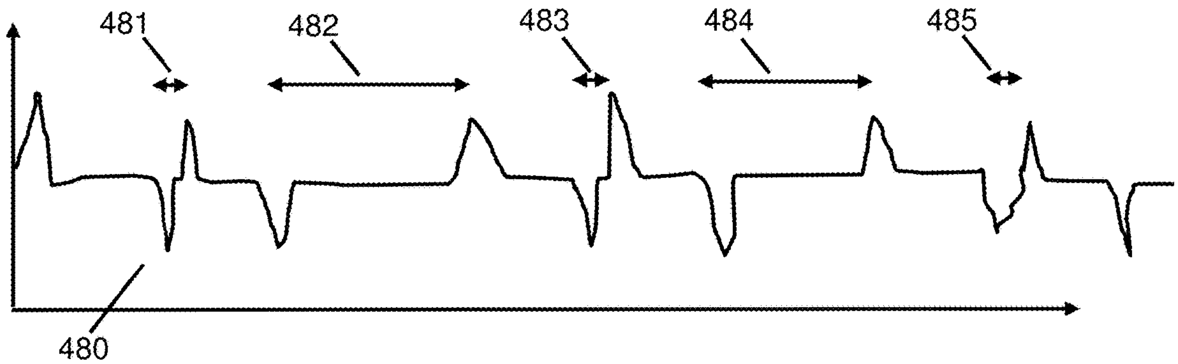
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FIG. 4F

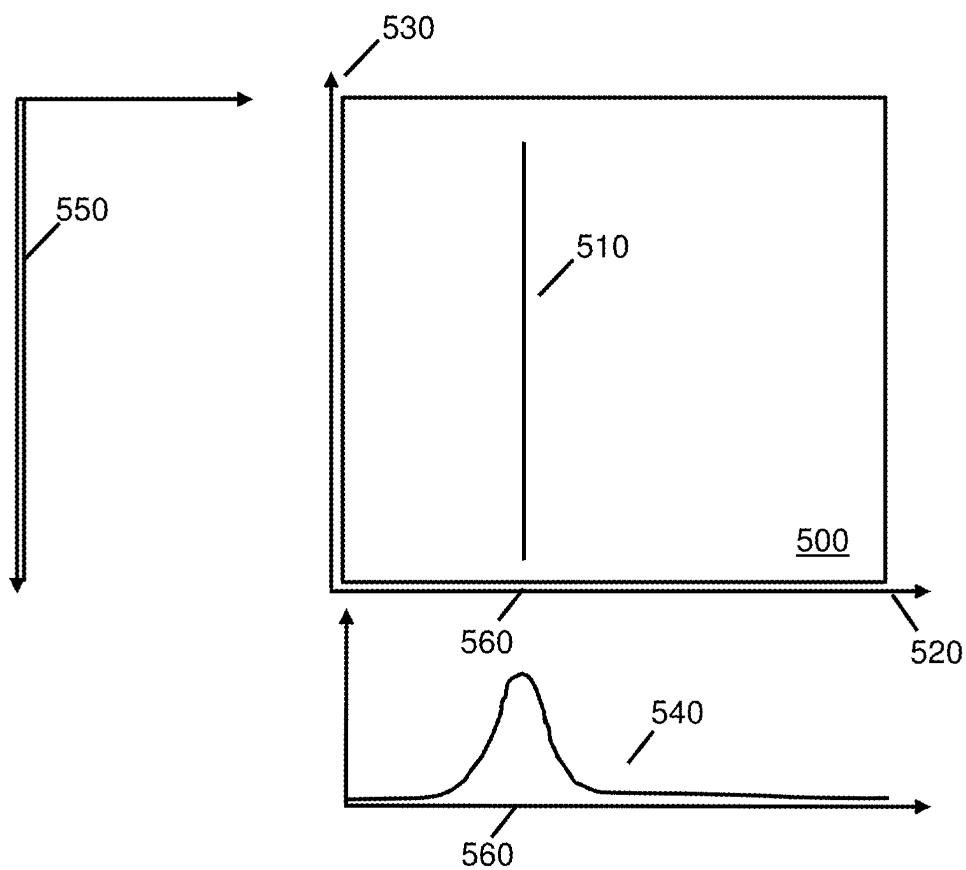


FIG. 5

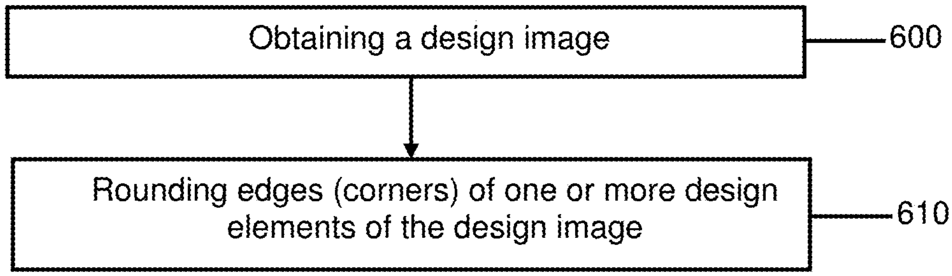
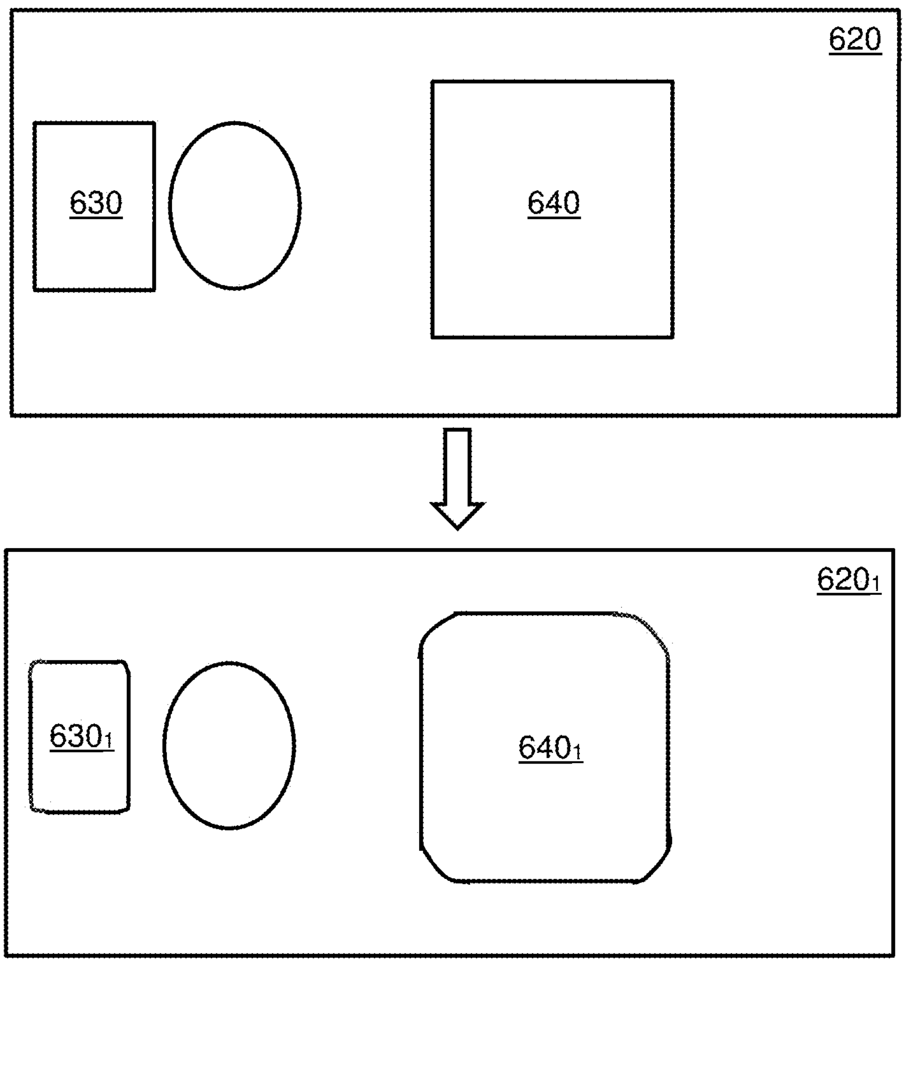

Obtaining a design image
600
Rounding edges (corners) of one or more design elements of the design image
610

FIG. 6A


620
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630_1
640_1

FIG. 6B

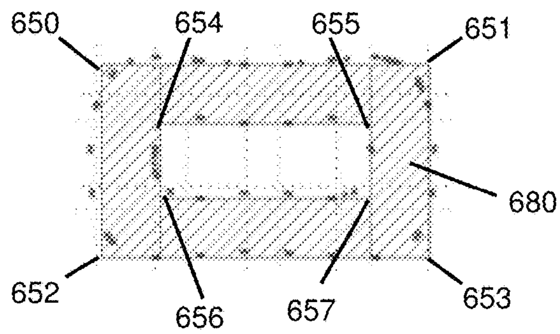


FIG. 6C

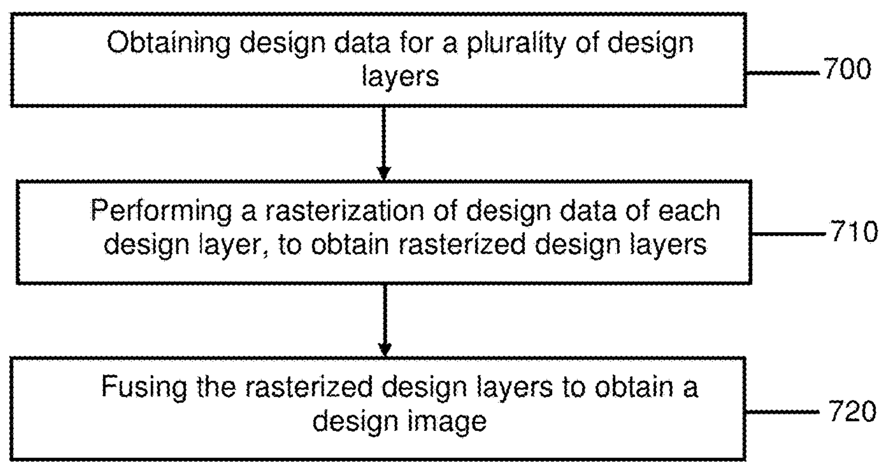


FIG. 7

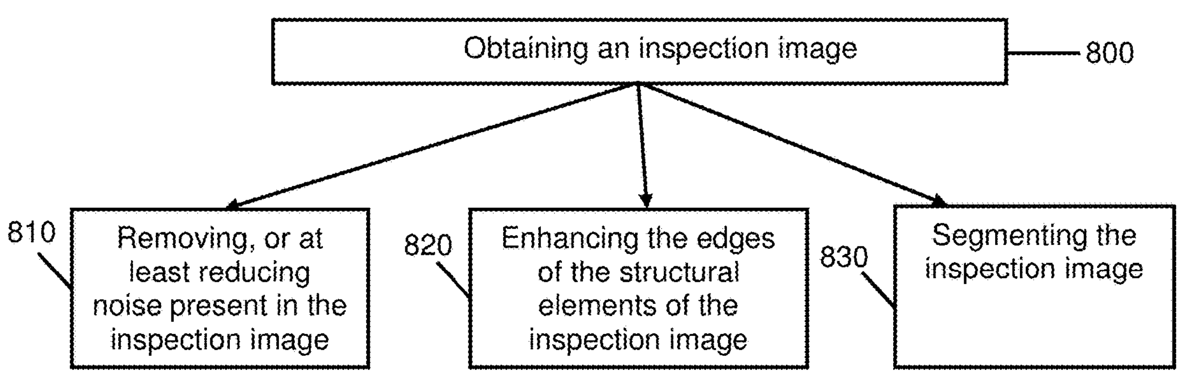


FIG. 8

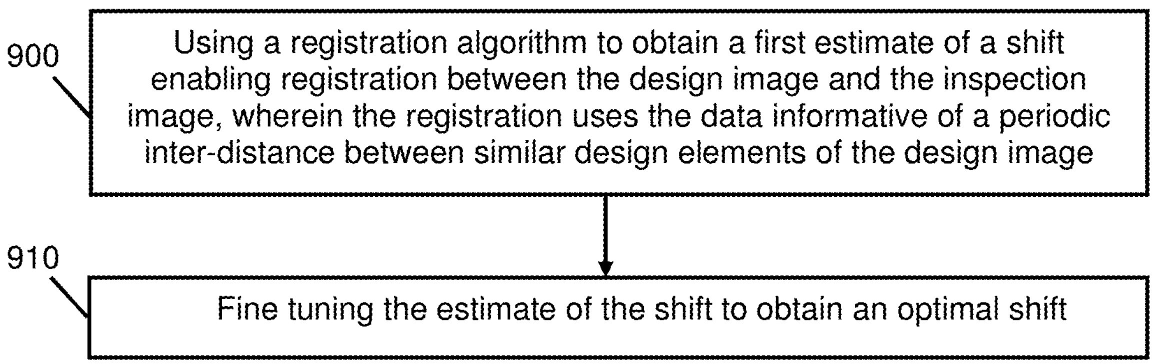
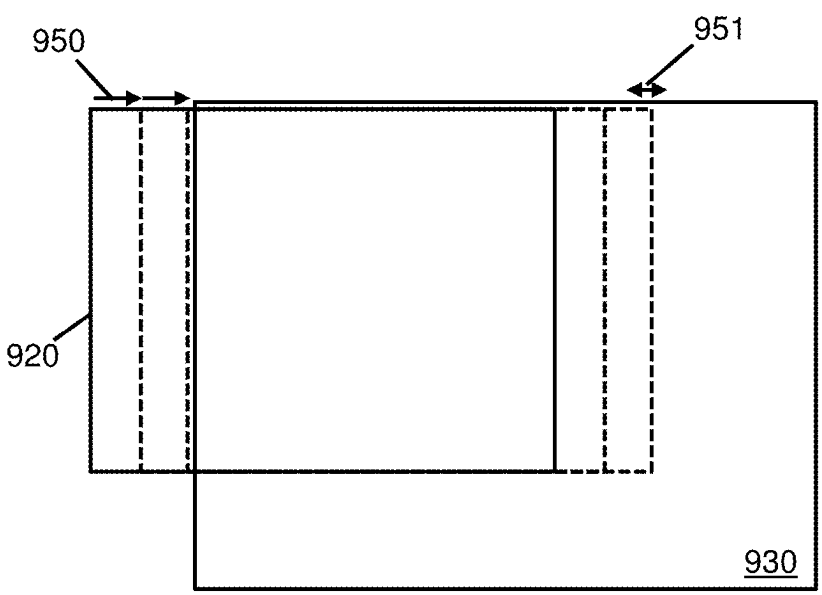

900
Using a registration algorithm to obtain a first estimate of a shift enabling registration between the design image and the inspection image, wherein the registration uses the data informative of a periodic inter-distance between similar design elements of the design image
910
Fine tuning the estimate of the shift to obtain an optimal shift

FIG. 9A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951
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930

FIG. 9B

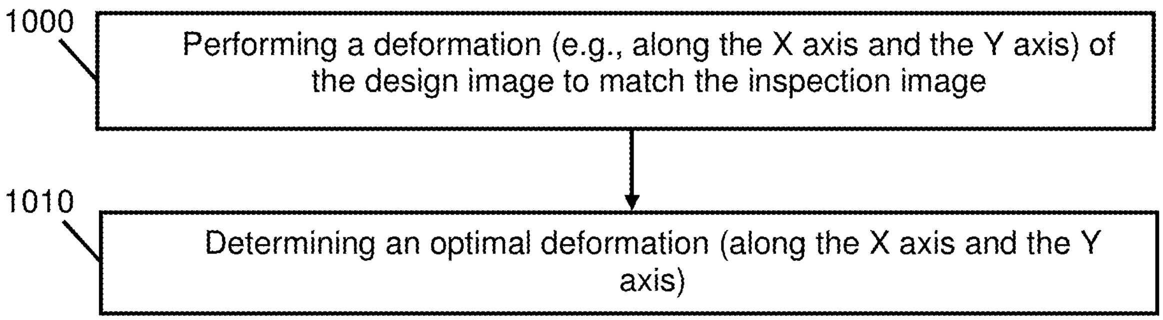

FIG. 10A

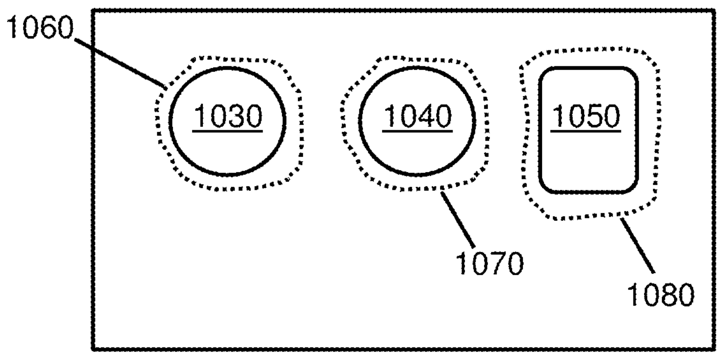

FIG. 10B

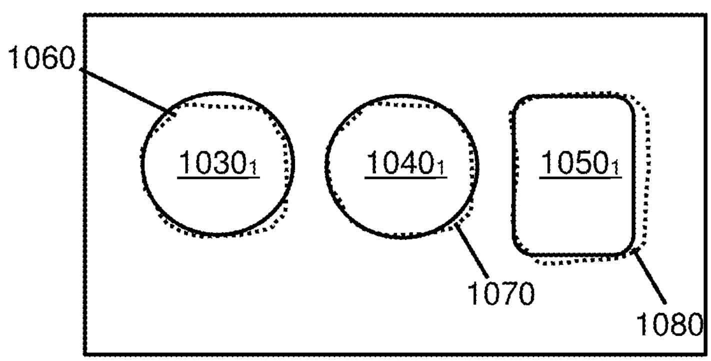

FIG. 10C

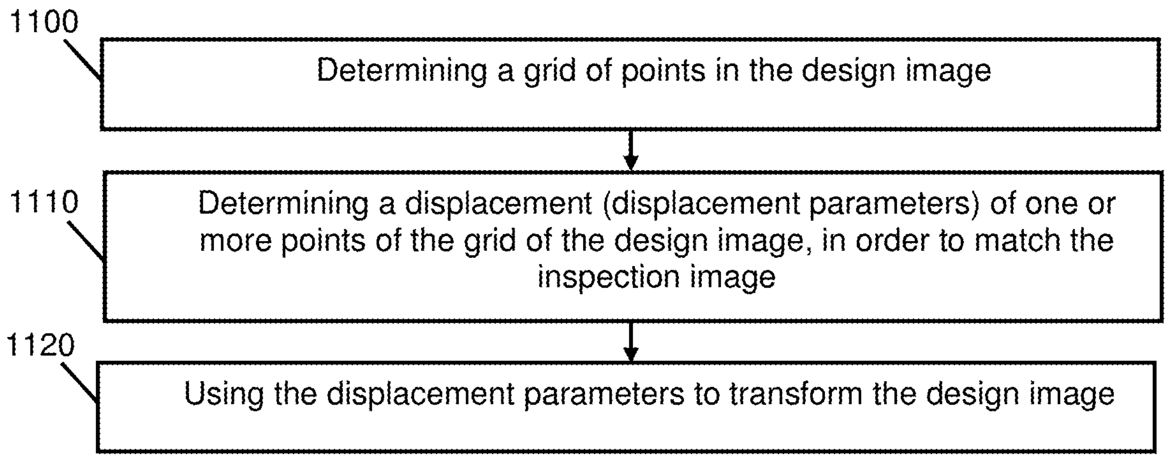

FIG. 11A

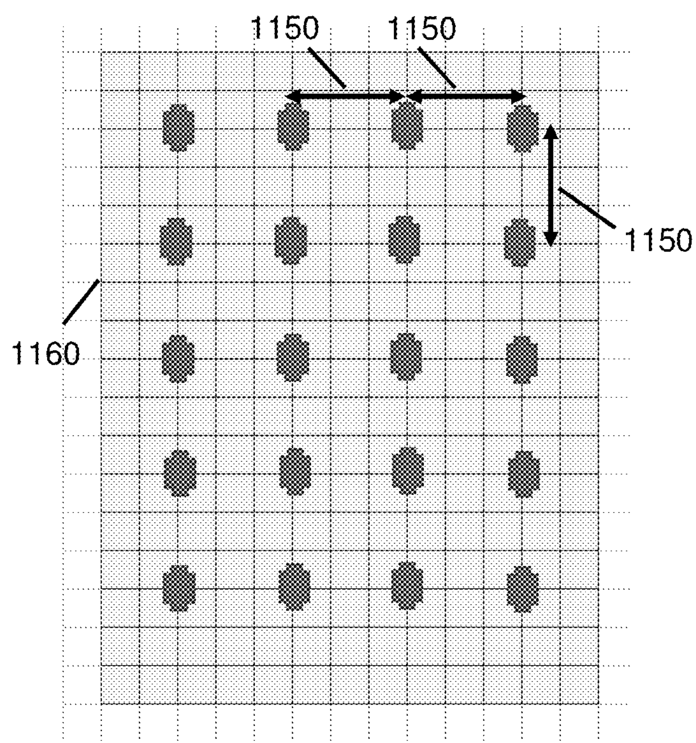

FIG. 11B

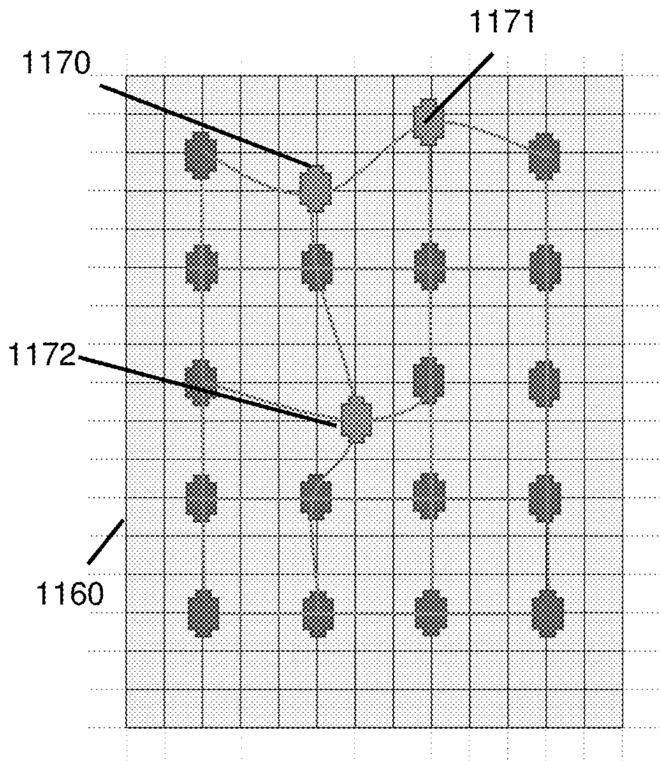

FIG. 11C

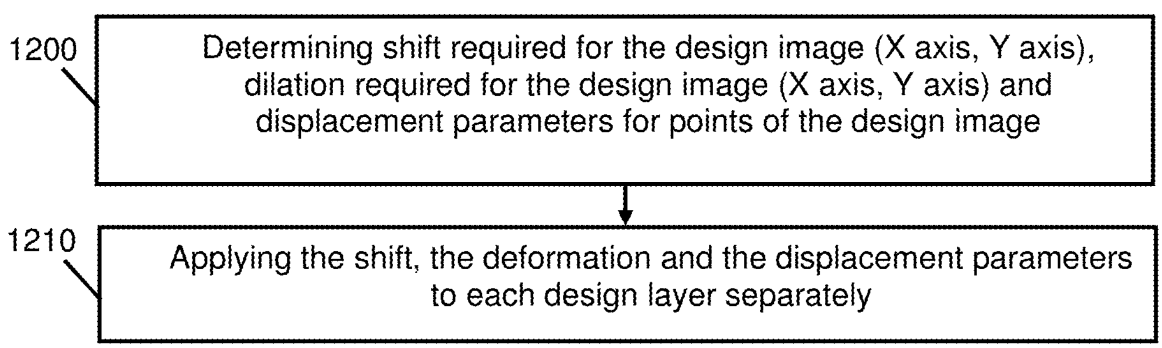

FIG. 12A

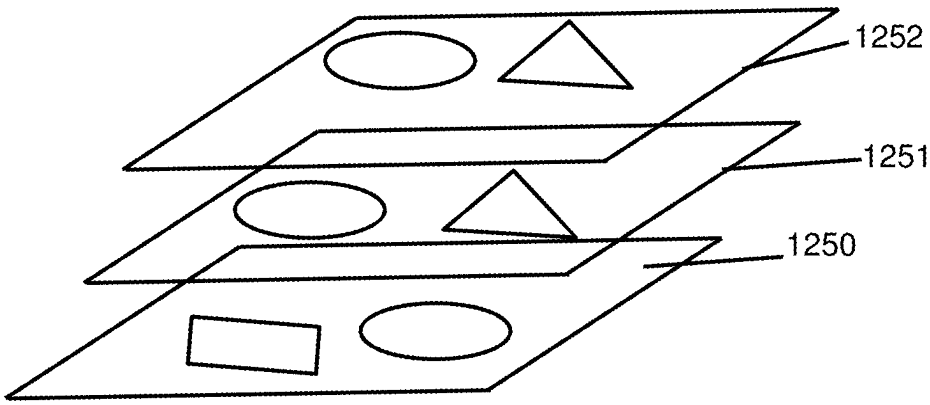

FIG. 12B

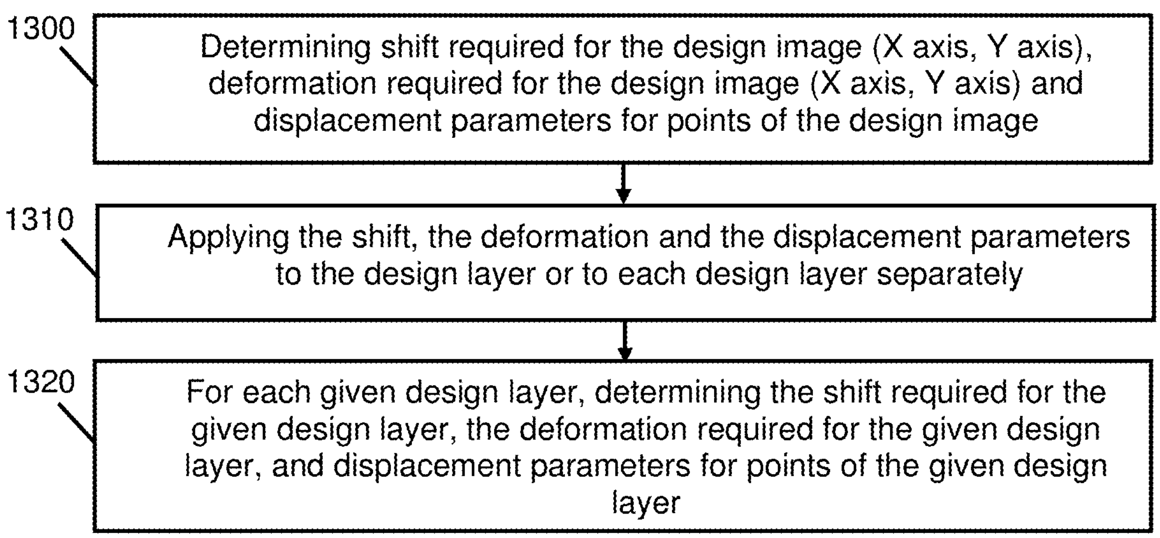

FIG. 13

REGISTRATION BETWEEN AN INSPECTION IMAGE AND A DESIGN IMAGE

TECHNICAL FIELD

[0001] The presently disclosed subject matter relates, in general, to the field of examination of a specimen, and more specifically, to automating the examination of a specimen.

BACKGROUND

[0002] Current demands for high density and performance associated with ultra large scale integration of fabricated devices require submicron features, increased transistor and circuit speeds, and improved reliability. Such demands require formation of device features with high precision and uniformity, which, in turn, necessitates careful monitoring of the fabrication process, including automated examination of the devices while they are still in the form of semiconductor wafers.

[0003] Examination processes are used at various steps during semiconductor fabrication to measure dimensions of the specimens (metrology), and/or to detect and classify defects on specimens (e.g., Automatic Defect Classification (ADC), Automatic Defect Review (ADR), etc.).

GENERAL DESCRIPTION

[0004] In accordance with certain aspects of the presently disclosed subject matter, there is provided a system comprising one or more processing circuitries configured to obtain an inspection image of a semiconductor specimen, and a design image or design data, informative of a plurality of design elements, determine data D_{pitch} informative of a periodic distance between design elements of the plurality of design elements, which are associated with a shape meeting a similarity criterion, and use the data D_{pitch} to obtain registration data between the design image or the design data, and the inspection image.

[0005] According to some examples, the design image or the design data are informative of a plurality of design layers, wherein the system is configured to determine, for each given design layer of the plurality of design layers, given registration data between the given design layer and the inspection image.

[0006] According to some examples, the system is configured to determine a derivative signal corresponding to a derivative of a pixel intensity signal associated with the design image or with the design data, and to use the derivative signal to determine data D_{pitch}.

[0007] According to some examples, the system is configured to determine a correspondence between the design image and the inspection image, for different shifts of the design image relative to the inspection image, wherein amplitude of the different shifts has been determined based on data D_{pitch}.

[0008] According to some examples, determining a correspondence between the design image and the inspection image comprises determining mutual information between the design image and the inspection image.

[0009] According to some examples, the system is configured to determine a correspondence between the design image and the inspection image, for different successive positions of the design image relative to the inspection image, wherein each position of these successive positions differs from a previous position by a shift which is equal to or smaller than half said periodic distance.

[0010] According to some examples, determining a correspondence between the design image and the inspection image comprises determining mutual information between the design image and the inspection image.

[0011] According to some examples, the system is configured to determine a correspondence between the design image and the inspection image, for different successive positions of the design image relative to the inspection image, wherein each position of these successive positions differs from a previous position by a shift which is equal to or smaller than half said periodic distance.

[0012] According to some examples, the system is configured to determine a correspondence between the design image and the inspection image, for different first successive positions of the design image relative to the inspection image, wherein each position of these first successive positions differs from a previous position by a first shift value, to obtain a first estimate of a registered position of the design image with respect to the inspection image, and determine a correspondence between the design image and the inspection image, for different second successive positions of the design image relative to the inspection image, located around said first estimate of the registered position, wherein each position of these second successive positions differs from a previous position by a second shift value, smaller than the first shift value, to obtain a second estimate of a registered position of the design image with respect to the inspection image.

[0013] According to some examples, for at least one given design element of the design elements, the system is configured to convert edges of the given design element into rounded edges, wherein a curvature of the rounded edges is selected based on one or more dimensions of the given design element.

[0014] According to some examples, the inspection image comprises a plurality of structural elements, wherein the system is configured to perform at least one of (i) or (ii): (i) perform a reduction of noise present in the inspection image, wherein said reduction depends on one or more dimensions of the structural elements, or (ii) perform an enhancing of edges of one or more of the structural elements, wherein said enhancing depends on one or more dimensions of the structural elements.

[0015] According to some examples, the system is configured to detect presence of one or more horizontal or vertical lines in the design image or in the design data, and use this detection to determine the registration data between the design image or the design data and the inspection image.

[0016] According to some examples, the registration data comprise data informative of a shift of the design image or of the design data, data informative of a deformation of one or more of the plurality of design elements, and displacement parameters of one or more points of the design image or of the design data.

[0017] According to some examples, the system is configured to determine a deformation enabling a match between the design elements and structural elements of the inspection image according to a matching criterion.

[0018] According to some examples, the system is configured to determine a grid of points in the design image, determine displacement parameters of a plurality of points of the grid, in order to match the inspection image according to a matching criterion, wherein at least two points of the grid are associated with different displacement parameters, and use the displacement parameters to transform the design image or the design data.

[0019] According to some examples, a distance between adjacent points of the grid is equal to or larger than half a minimum distance between the design elements.

[0020] According to some examples, the design image or the design data is informative of a plurality of design layers,

[0021] According to some examples, the registration parameters are informative of at least one of a shift, a deformation, or displacement parameters of one or more points of the design image, wherein the system is configured to use said registration parameters to transform each design layer separately.

[0022] According to some examples, the design data is informative of a plurality of design layers, wherein the system is configured to rasterize the design data of the plurality of design layers, and combine them to obtain the design image, without requiring user input for defining pixel intensity in the design image.

[0023] In accordance with other aspects of the presently disclosed subject matter, there is provided a method comprising, by one or more processing circuitries, obtaining an inspection image of a semiconductor specimen, and a design image or design data, informative of a plurality of design elements, determining data D_{pitch} informative of a periodic distance between design elements of the plurality of design elements, which are associated with a shape meeting a similarity criterion, and using the data D_{pitch} to obtain registration data between the design image or the design data, and the inspection image.

[0024] According to some embodiments, the method can comprise one or more of the features above, described with reference to the system.

[0025] In accordance with other aspects of the presently disclosed subject matter, there is provided a non-transitory computer readable medium comprising instructions that, when executed by a computer, cause the computer to perform operations described with reference to the method above.

[0026] The proposed solution provides various technical advantages. At least some of them are listed hereinafter.

[0027] According to some examples, the proposed solution enables efficient and accurate registration between an inspection image (e.g., SEM image) of a semiconductor specimen and a design image.

[0028] According to some examples, the proposed solution enables automatic registration between an inspection image (e.g., SEM image) of a semiconductor specimen and a design image. In some examples, a fully automatic registration is obtained.

[0029] According to some examples, the proposed solution enables registration between a multi-layer design image and an inspection image (e.g., SEM image) of a semiconductor specimen.

[0030] According to some examples, the proposed solution enables registration of each layer of a multi-layer design image with an inspection image (e.g., SEM image).

[0031] According to some examples, the proposed solution does not require manual intervention of a user for matching each polygon of each layer of the design image with an inspection image. To the contrary, the proposed solution automatically determines registration parameters for each polygon of each layer.

[0032] According to some examples, the proposed solution does not require user intervention for defining pixel intensity of a design image obtained from design data.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] In order to understand the disclosure and to see how it may be carried out in practice, embodiments will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

[0034] FIG. **1** illustrates a generalized block diagram of an examination system in accordance with certain embodiments of the presently disclosed subject matter.

[0035] FIG. **2** illustrates a generalized flow-chart of a method of determining geometrical data informative of the design image.

[0036] FIG. **3**A illustrates a non-limitative example of a design image with repetitive design elements separated by a periodic distance (pitch distance).

[0037] FIG. **3**B illustrates a derivative of the pixel intensity of the design image of FIG. **3**A, which can be used to determine the periodic distance of the repetitive design elements of FIG. **3**A.

[0038] FIG. **4**A illustrates a non-limitative example of a design image with repetitive groups of design elements separated by a periodic distance (pitch distance).

[0039] FIG. **4**B illustrates a derivative of the pixel intensity of the design image of FIG. **4**A, which can be used to determine the periodic distance of the repetitive groups of design elements of FIG. **4**A.

[0040] FIG. **4**C illustrates a non-limitative example of a design image with a plurality of design elements.

[0041] FIG. **4**D illustrates a derivative of the pixel intensity of the design image of FIG. **4**C, which can be used to determine the distance between adjacent design elements of the design image of FIG. **4**C.

[0042] FIG. **4**E illustrates a non-limitative example of a design image with a plurality of design elements.

[0043] FIG. **4**F illustrates a derivative of the pixel intensity of the design image of FIG. **4**E, which can be used to determine one or more dimensions of the design elements of FIG. **4**E.

[0044] FIG. **5** illustrates a non-limitative example of a method of detecting lines in a design image.

[0045] FIG. **6**A illustrates a generalized flow-chart of a method of rounding edges of one or more design elements of a design image.

[0046] FIG. **6**B illustrates a non-limitative example of the method of FIG. **6**A.

[0047] FIG. **6**C illustrates another non-limitative example of the method of FIG. **6**A.

[0048] FIG. **7** illustrates a generalized flow-chart of generating a design image.

[0049] FIG. **8** illustrates a generalized flow-chart of a method of processing an inspection image.

[0050] FIG. **9**A illustrates a generalized flow-chart of a method of determining a shift between the design image and the inspection image, for registering the design image with the inspection image.

[0051] FIG. **9**B illustrates a non-limitative example of the method of FIG. **9**A.

[0052] FIG. **10**A illustrates a generalized flow-chart of a method of determining a deformation between the design image and the inspection image, for registering the design image with the inspection image.

[0053] FIGS. **10**B and **10**C illustrate non-limitative examples of the method of FIG. **10**A.

[0054] FIG. **11**A illustrates a generalized flow-chart of a method of determining a deformable registration between the design image and the inspection image.

[0055] FIGS. **11**B and **11**C illustrate non-limitative examples of the method of FIG. **11**A.

[0056] FIG. **12**A illustrates a generalized flow-chart of a method of transforming each design layer of a design image separately.

[0057] FIG. **12**B illustrates a non-limitative example of a design image with multiple design layers.

[0058] FIG. **13** illustrates a generalized flow-chart of a method of registering, separately, each design layer of a design image with an inspection image.

DETAILED DESCRIPTION OF EMBODIMENTS

[0059] Registration between images is required in various applications. In some cases, it can be required to register a design image (e.g., CAD image) with an inspection image (e.g., SEM image) of a semiconductor specimen. In prior art systems, registration between a CAD image and a SEM image required manual intervention of the user, in order to attempt to match, in a manual way, the polygons of the CAD image with the SEM image. New systems and methods are provided hereinafter in the field of image registration, which can be performed automatically (or at least with less intervention of the user). The solution is applicable to multi-layers design images. According to some examples, the solution provides, in an automatic way, optimal transformations of the CAD image (shift, deformation, displacement of points) to match the SEM image. Such registration can be used for various applications, such as, but not limited to, defect detection, monitoring of the manufacturing process, etc. Once registration data between the design image and the inspection image have been determined (which reflect the deviation between the specimen and the intended design), they can be used to modify or improve the manufacturing process.

[0060] According to some examples, and as further explained hereinafter, a periodic distance (pitch distance) between repetitive design elements of a design image is determined. A correspondence between the design image and an inspection image, for different shifts of the design image relative to the inspection image, is determined. The amplitude of each shift is determined based on this pitch distance (in some examples, each shift is selected to be equal to or smaller than half the pitch distance). Other processing operations, such as deformation of the design elements and displacement of points of the design elements, can be performed to register automatically the design image with the inspection image.

[0061] Attention is drawn to FIG. **1** illustrating a functional block diagram of an examination system in accordance with certain embodiments of the presently disclosed subject matter. The examination system **100** illustrated in FIG. **1** can be used for examination of a specimen (e.g., of a wafer and/or parts thereof) as part of the specimen fabrication process. The illustrated examination system **100** comprises computer-based system **103** capable of automatically determining metrology-related and/or defect-related information using images obtained during specimen fabrication. System **103** can be operatively connected to one or more low-resolution examination tools **101** and/or one or more high-resolution examination tools **102** and/or other examination tools. The examination tools are configured to capture images and/or to review the captured image(s) and/or to enable or provide measurements related to the captured image(s). System **103** can be further operatively connected to CAD server **110** and data repository **109**.

[0062] System **103** includes a processing circuitry **104**, which includes a processor (or a plurality of processors) and a memory (or a plurality of memories). The processing circuitry **104** is configured to provide all processing necessary for operating the system **103** as further detailed hereinafter (see methods described in FIGS. **2**, **6**A, **7**, **8**, **9**A, **10**A, **11**A, **12**A and **13** which can be performed at least partially by system **103**).

[0063] System **103** is configured to receive input data. Input data can include data (and/or derivatives thereof and/or metadata associated therewith) produced by the examination tools and/or data produced and/or stored in one or more data repositories **109** and/or in CAD server **110** and/or another relevant data depository. It is noted that input data can include images (e.g., captured images, images derived from the captured images, simulated images, synthetic images, etc.) and associated numeric data (e.g., metadata, hand-crafted attributes, etc.). It is further noted that image data can include data related to a layer of interest and/or to one or more other layers of the specimen.

[0064] By way of non-limiting example, a specimen can be examined by one or more low-resolution examination machines **101** (e.g., an optical inspection system, low-resolution SEM, etc.). The resulting data (low-resolution image data **121**), informative of low-resolution images of the specimen, can be transmitted-directly or via one or more intermediate systems—to system **103**. Alternatively, or additionally, the specimen can be examined by a high-resolution machine **102**, such as a scanning electron microscope (SEM) or Atomic Force Microscopy (AFM)). The resulting data (high-resolution image data **122**), informative of high-resolution images of the specimen, can be transmitted-directly, or via one or more intermediate systems—to system **103**.

[0065] It is noted that image data can be received and processed together with metadata (e.g., pixel size, text description of defect type, parameters of image capturing process, etc.) associated therewith.

[0066] Upon processing the input data (e.g. low-resolution image data and/or high-resolution image data, together with other data, such as, for example, design data, synthetic data, etc.), system **103** can send instructions **123** and/or **124** to any of the examination tool(s), store the results (such as registration data between an image of a specimen and a design image) in a storage system **107**, render the results via a computer-based graphical user interface GUI **108**, and/or send the results to an external system.

[0067] Those versed in the art will readily appreciate that the teachings of the presently disclosed subject matter are not bound by the system illustrated in FIG. **1**; equivalent and/or modified functionality can be consolidated or divided in another manner and can be implemented in any appropriate combination of software with firmware and/or hardware.

[0068] Without limiting the scope of the disclosure in any way, it should also be noted that the examination tools can be implemented as inspection machines of various types, such as optical imaging machines, electron beam inspection machines, and so on. In some cases, the same examination tool can provide low-resolution image data and high-resolution image data. In some cases, at least one examination tool can have metrology capabilities.

[0069] It is noted that the examination system illustrated in FIG. **1** can be implemented in a distributed computing environment, in which the aforementioned functional modules shown in FIG. **1** can be distributed over several local and/or remote devices, and can be linked through a communication network. It is further noted that in other embodiments at least some examination tools **101** and/or **102**, data repositories **109**, storage system **107** and/or GUI **108** and/or CAD server **110** can be external to the examination system **100** and operate in data communication with system **103**. System **103** can be implemented as stand-alone computer(s) to be used in conjunction with the examination tools. Alternatively, the respective functions of the system can, at least partly, be integrated with one or more examination tools.

[0070] Attention is now drawn to FIG. **2**, which describes a method of determining information on a design image and/or on design data, which can be used to register the design image (or the design data) with an inspection image (e.g., SEM image).

[0071] The design image includes a plurality of design elements (such as rectangles, triangles, circles, lines) which are informative of real structural elements (e.g., gates, contacts, electrical lines, etc.). The design data is also informative of a plurality of design elements. The design image and the design data are informative of a plurality of design elements. A design element includes one or more geometrical shapes which are informative of the intended design (desired design) of one or more structural elements (e.g., gates, contacts, etc.) of a specimen to be manufactured.

[0072] The design image and the design data can be informative of a plurality of design layers. A design layer includes a plurality of design elements and corresponds to the intended design of a real layer of a specimen to be manufactured. In some examples, each design layer of the plurality of design layers is defined by design data (such as CAD data). The design image can correspond to an image obtained, based on the CAD data of the plurality of layers. The design image generally includes pixels (each associated with a pixel intensity), informative of the plurality of design elements, whereas the design data generally includes a plurality of polygons, informative of the plurality of design elements.

[0073] The method of FIG. **2** includes obtaining (operation **200**) at least one of a design image or design data (e.g., CAD data) usable to generate the design image.

[0074] The method of FIG. **2** includes determining various geometrical data informative of the design elements. Note that the method of FIG. **2** can be performed on the design image. In some examples, the design image results from the fusion of design data of a plurality of design layers, after rasterization of the design data of each design layer. In some examples, the method of FIG. **2** can be performed on the design data (CAD data, in which the polygons can be rasterized) of each design layer separately.

[0075] According to some examples, the method of FIG. **2** includes determining (operation **201**) data (D_{pitch}) informative of a periodic distance (also called pitch distance) between design elements of the design image, which are associated with a shape meeting a similarity criterion. In other words, the periodic distance between repeated design elements is determined. This distance is periodic since it is present repetitively between similar design elements of the design image.

[0076] Design elements with a shape meeting a similarity criterion can correspond e.g., to a plurality of squares, or to a plurality of triangles, or to a plurality of circles, etc. This is not limitative. The similarity criterion can dictate that the design elements have the same shape (circular, triangular, etc.) and the same size (same radius for a circle, same side length for a triangle, etc.). This is not limitative.

[0077] Note that the periodic distance can be computed along one axis (e.g., horizontal X axis of the design image, or vertical Y axis of the design image), or along two axes (e.g., horizontal and vertical axes of the design image). Note that the periodic distance can be different along the horizontal X axis and along the vertical Y axis, or can be the same.

[0078] A non-limitative example is illustrated in FIG. **3**A. Assume that the design image **300** includes a plurality of squares $\mathbf{300}_1$, $\mathbf{300}_2$, $\mathbf{300}_3$. The distance **310** between the first square $\mathbf{300}_1$ and the second square $\mathbf{300}_2$ is equal to the distance **310** between the second square $\mathbf{300}_2$ and the third square $\mathbf{300}_3$. Operation **201** can include determining the value of this periodic distance **310** between similar squares of the design image **300**.

[0079] In some examples, operation **201** can include determining the derivative of the pixel intensity of the design image along a horizontal axis of the design image (see axis **320** in FIG. **3**). Note that this derivative can be determined for each of a plurality of different horizontal axes (see for example axes **320** and $\mathbf{320}_1$), that it to say for different coordinates of the vertical Y axis **307**. A plurality of derivative signals is therefore obtained, which can be processed, as explained hereinafter.

[0080] A non-limitative example of a derivative signal **350** is illustrated in FIG. **3**B. The derivative signal **350** corresponds to the derivative of the pixel intensity of the design image **300** along the horizontal axis **320** (or $\mathbf{320}_1$). As visible in FIG. **3**B, the derivative signal **350** includes three main positive peaks $\mathbf{360}_1$, $\mathbf{360}_2$ and $\mathbf{360}_3$. The first positive peak $\mathbf{360}_1$ corresponds to the left side $\mathbf{301}_1$ of the first square $\mathbf{300}_1$, the second positive peak $\mathbf{360}_2$ corresponds to the left side $\mathbf{302}_1$ of the second square $\mathbf{300}_2$ and the third positive peak $\mathbf{360}_3$ corresponds to the left side **3031** of the third square $\mathbf{300}_3$. As also visible in FIG. **3**B, the derivative signal **350** includes three main negative peaks $\mathbf{370}_1$, $\mathbf{370}_2$ and $\mathbf{370}_3$. The first negative peak $\mathbf{370}_1$ corresponds to the right side $\mathbf{301}_2$ of the first square $\mathbf{300}_1$, the second negative peak $\mathbf{370}_2$ corresponds to the right side $\mathbf{302}_2$ of the second square $\mathbf{300}_2$, and the third negative peak $\mathbf{370}_3$ corresponds to the right side $\mathbf{302}_3$ of the third square $\mathbf{300}_3$.

[0081] According to some examples, the periodic distance **310** can be computed by determining the periodic distance between consecutive positive main peaks along the horizontal axis **333** (see first distance **380** between the first peak $\mathbf{360}_1$ and the second peak $\mathbf{360}_2$, and second distance **381** between the second peak $\mathbf{360}_2$ and the third peak $\mathbf{360}_3$). The periodic distance **310** can correspond, e.g., to the average between the first distance **380** and the second distance **381**.

[0082] Although FIG. **3**A and FIG. **3**B depict an example in which the periodic distance is computed along a horizontal axis of the image (parallel to the horizontal X axis **308**), the same method can be used to determine the periodic distance along a vertical axis (parallel to the vertical Y axis **307**). In particular, the derivative of the pixel intensity can be determined for each of a plurality of vertical axes (see **370_1** and **370_2**), thereby obtaining a plurality of derivative signals. The periodic distance can be computed by determining the periodic distance between consecutive positive main peaks in each of the derivative signals.

[0083] In some examples, operation **201** can include determining data informative of a periodic distance between groups of design elements of the design image, wherein the various groups are similar in that each group includes design elements with a shape similar (according to a similarity criterion) to the shape of the design elements of each of the other groups. In particular, each group can include a sequence of design elements distributed along an axis (e.g., X axis, or Y axis), which is similar to the sequence of design elements present in each of the other groups.

[0084] A non-limitative example is illustrated in FIG. **4**A. In this example, the design image **400** includes a first group **401** of design elements (first square **401_1** and first circle **401_2**), a second group **402** of design elements (second square **402_1** and second circle **402_2**) and a third group **403** of design elements (third square **403_1** and second circle **403_2**). The first, second, and third groups **401**, **402**, and **403** include design elements which meet a similarity criterion among the different groups.

[0085] The periodic distance between the different groups of design elements is noted **410** and corresponds to the distance between the first group **401** of design elements and the second group **402** of design elements, and to the distance between the second group **402** of design elements and the third group **403** of design elements.

[0086] In order to compute the periodic distance **410**, operation **201** can include determining the derivative **480** of the pixel intensity of the design image **400** along a horizontal axis (X axis) of the design image (see axis **420** in FIG. **4**A). As mentioned above, this derivative can be determined for each of a plurality of different horizontal axes, that it to say for different coordinates along the vertical axis. A plurality of derivative signals is therefore obtained, which can be processed, as explained hereinafter.

[0087] The signal **480** includes a plurality of positive peaks (corresponding to the respective left sides of the squares, and to the respective extreme left points of the circles present along the horizontal axis **420**), and a plurality of negative peaks (corresponding to the respective right edges of the squares, and to the respective extreme right points of the circles present along the horizontal axis **420**). Each group (**401**, **402**, **203**) of design elements is represented by the same pattern of peaks (the pattern includes a sequence of a positive peak, a negative peak, a positive peak, and a negative peak). The distance between the first positive peak of consecutive groups of design elements corresponds to the periodic distance **410** (see distance **450** which is the distance between the first positive peak **470** of the pattern informative of the first group of design elements and the first positive peak **471** of the pattern informative of the second group of design elements, and distance **451** which is the distance between the first positive peak **471** of the pattern informative of the second group of design elements, and the first positive peak **472** of the pattern informative of the third group of design elements). The periodic distance **410** can correspond, e.g., to the average between the first distance **450** and the second distance **451**.

[0088] According to some examples, the method of FIG. **2** can include (see operation **202**) determining data informative of distances between consecutive design elements (along one axis, such as horizontal X axis or vertical Y axis, or along two axes X and Y). Note that in contrast to operation **201**, consecutive design elements can correspond to design elements with a different shape. Operation **202** can include outputting a histogram of distances, from which various data can be computed (average distance between consecutive design elements, minimal or maximal distance between consecutive design elements, variance of the distances, etc.). In some examples, the minimal distance between consecutive design elements is computed for the whole design image (or design data).

[0089] According to some examples, operation **202** can be performed by computing the derivative of the pixel intensity (e.g., along the X and/or Y axis) of the design image, and determining the distance between each negative peak (corresponding to the right side or to the extreme right point of a design element) and the next positive peak (corresponding to the left side or to the extreme left point of the next/adjacent design element), although they belong to design elements associated with different shapes. In the vertical axis, this distance corresponds to the distance between the bottom side, bottom edge, or bottom extreme point of a design element, and the top side, or top edge, or top extreme point of the adjacent design element along the vertical axis.

[0090] In the examples of FIGS. **4**C and **4**D, the following distances are computed: distance **481** (between the right side of the first square **401_1** and the extreme left point of the first circle **401_2**), distance **482** (between the right side of the first circle **401_2** and the extreme left point of the second square **402_1**), distance **483** (between the right side of the second square **402_1** and the extreme left point of the second circle **402_2**), distance **484** (between the extreme right point of the second circle **402_2** and the left side of the third square **403_1**), and distance **485** (between the right side of the third square **403_1** and the extreme left point of the third square **403_2**).

[0091] According to some examples, the method of FIG. **2** can include (see operation **203**) determining data informative of dimensions of the design elements (along one axis, e.g., horizontal X or Y axis, or along two axes X and Y of the design image). In some examples, this data can be used to determine the largest width and/or largest height among the design elements. In some examples, this data can be used to determine the smallest width and/or smallest height among the design elements. In some examples, this data can be used to determine the largest critical dimension (CD) and/or the smallest critical dimension (CD) among the design elements.

[0092] According to some examples, operation **203** can be performed by computing the derivative of the pixel intensity (e.g., along the X and/or Y axis), and determining the distance between each positive peak and the next negative peak. In the horizontal axis, this distance corresponds to the distance between the left side, or left edge, or left extreme point of a design element and the right side, or right edge, or right extreme point of the same design element. In the vertical axis, this distance corresponds to the distance between top side, or top edge, or top extreme point of a design element and the bottom side, or bottom edge, or bottom extreme point of the same design element.

[0093] In the examples of FIGS. **4**E and **4**F, the following dimensions are computed: dimension **491** (between the right side of the square 401_1 and the left side of the square 401_1, or between the right side of the square 402_1 and the left side of the square 402_1, or between the right side of the square 403_1 and the left side of the square 403_1) and dimension **492** (between the extreme right point of the circle 401_2 and the extreme left point of the circle 401_1, or between the extreme right point of the circle 402_2 and the extreme left point of the circle 402_1, or between the extreme right point of the circle 403_1 and the extreme left point of the circle 403_2).

[0094] According to some examples, the method of FIG. **2** can include (see operation **204**) determining the presence of one or more lines in the design image, such as horizontal lines (along the horizontal X axis of the design image) and/or vertical lines (along the vertical Y axis of the design image).

[0095] A non-limitative example of operation **204** is illustrated in FIG. **5**, in which the design image **500** includes a vertical line **510**. In the example of FIG. **5**, the derivative **540** of the pixel intensity along the horizontal X axis **520** and the derivative **550** of the pixel intensity along the vertical Y axis **530** are computed. As mentioned above, the derivative can be computed along various horizontal lines of the design image and along various vertical lines of the design image.

[0096] It can be seen that at the position **560** along the horizontal axis **520**, a peak is present, whereas no peak is present in the derivative signal **550** computed along the vertical axis **530**. This indicates the presence of a vertical line at position **560** in the design image. The same principles can be used to detect a horizontal line (for which a peak is present in the derivative computed along the vertical axis, and no peak is present in the derivative computed along the horizontal axis).

[0097] In some examples, it is possible to use a clustering algorithm (e.g., K means, trained machine learning model, such as trained deep neural network, or other algorithms) to cluster the design elements, based on their shapes. This can be used to identify the design elements with a similar shape (e.g., squares, triangles, etc.). Once the position of the design elements with a similar shape is known, it is possible to determine the periodic distance between the design elements with the same shape and/or the distance between consecutive/adjacent design elements.

[0098] Attention is now drawn to FIG. **6**A.

[0099] The method of FIG. **6**A includes obtaining (operation **600**) a design image and/or design data (usable to generate the design image), informative of design elements. The design image and/or the design data can correspond to the design image and design data processed according to the method of FIG. **2**.

[0100] The method of FIG. **6**A further includes rounding (operation **610**) edges (that is to say, corners) of one or more design elements. This operation corresponds to a smoothing operation of the edges. The shape and location of the different design elements may have been determined beforehand (using e.g., a clustering algorithm), as explained above with reference to FIG. **2**. This shape analysis can therefore be used to determine the edges that need to be rounded at operation **610**. Rounding of the edges can include using Elliptic Fourier features of a closed contour.

[0101] The method of FIG. **6**A can be performed on the design data of each design layer separately (the polygons of each design data may have been rasterized beforehand). In some cases, the method of FIG. **6**A can be performed on the design image (which results from the fusion of the design data of the different design layers).

[0102] In some examples, the method of FIG. **6**A can further benefit from the processing performed in FIG. **2**. As mentioned with respect to operation **203** in FIG. **2**, the dimensions of the various design elements (present in the design data or in the design image) can be determined. Rounding of the edges of the design elements can depend on the dimensions of the design elements. In other words, an adaptive edge rounding can be performed. In some examples, the larger the dimensions of a design element, the stronger the rounding applied to its edges (the radius of curvature of the rounded edges is high). Conversely, the smaller the dimensions of a design element, the weaker the rounding applied to its edges (the radius of curvature of the rounded edges is small). This is visible in the non-limitative example of FIG. **6**B, in which a design layer **620** includes a first square **630** and a second square **640**.

[0103] In some examples, the rounding of the edges can depend on the field of view of the inspection image (which has to be registered with the design image). Indeed, by the nature of the lithographic process (the reproducibility of the lithographic process is limited by the wavelength and the size of the structures in the mask), the resultant patterns obtained after the lithographic process correspond to patterns that are smoother versions of the design intent. The amount of rounding of the edges of the patterns depends on the size of the patterns relative to the field of view.

[0104] Assume that the number of structures to be measured reminds constant, and that the process technology is changed (corresponding to a shrink of the patterns). Applicant has discovered that the amount of roundedness increases when the size of the pattern shrinks.

[0105] The design layer **620** is processed to obtain the modified design layer **6201**, in which the edges of the first square **630** have been rounded to obtain the first square **6301**, and the edges of the second square **640** have been rounded to obtain the second square **6401**. As visible in FIG. **6**B, since the dimensions of the second square **640** are larger than the dimensions of the first square **630**, the edges of the second square **640** are more rounded than the edges of the first square **630**.

[0106] Note that the edges of the design element which are rounded can correspond to external edges, but can also correspond to internal edges located within the design element. This is illustrated in FIG. **6**C, in which four external edges (**650**, **651**, **652** and **653**) of the design element **680** are rounded, and four internal edges (**654**, **655**, **656** and **657**) of the design element **680** are rounded.

[0107] Attention is now drawn to FIG. **7**.

[0108] The method of FIG. **7** includes obtaining (operation **700**) design data informative of one or more design layers. The design data can correspond to the design data processed according to the method of FIG. **6**A, in which the edges of the design elements have been rounded, and to the design data as analyzed according to the method of FIG. **2**.

[0109] The method of FIG. **7** includes performing (operation **710**) a rasterization of the design data of each design layer (this is designated herein as performing a rasterization of each design layer). Rasterization includes taking a vector graphics image which includes shapes, and converting it into a raster image which is made up of pixels. In some examples, all the polygons belonging to the same design layer are assigned with similar pixel values. In some examples, the user input is not required for defining the pixel values of the rasterized layers. This is beneficial since this enables obtaining an automatic method.

[0110] The method of FIG. **7** further includes combining (this is also called fusing) the rasterized design layers to obtain a design image. The different rasterized design layers are combined into a common (single) two-dimensional plane in order to obtain the design image.

[0111] In some examples, it is possible to assign, in this combination, a respective weight to the pixel intensity of each respective rasterized design layer. For example, the least visible layer(s) (generally corresponding to the deepest layers) get a smaller weight than the most visible layer(s) (generally corresponding to the top layers). As a consequence, the least visible layer(s) gets a pixel intensity value smaller than that of the most visible layer(s).

[0112] In a conventional approach, rasterization of design data to obtain a design image requires the user to provide a yield value for each pixel of the different design layers. In other words, a high level of involvement of the user is required. In some examples, the method of FIG. **7** does not require the user to provide the yield value(s), and still enables registration of the design image with an inspection image. In some examples, this property can result from the fact that a specific metric is used hereinafter (mutual information) to determine correspondence between the design image (or design data) and the inspection image, which is insensitive to pixel values. This is however not limitative.

[0113] Attention is now drawn to FIG. **8**.

[0114] The method of FIG. **8** includes obtaining (operation **800**) an inspection image acquired by an examination tool (such as examination tool **101** or **102**). The inspection image includes a plurality of structural elements (e.g., gates, lines, contacts, etc.). The inspection image is for example a SEM image. As mentioned above, a registration between a design image and the SEM image has to be performed. Various operations performed on the design image and the SEM image are described to enable this registration. This registration can output registration data, which includes different transformations (e.g., shift, deformation, displacement parameters of different points) to be applied to the design image or to the design data to match (as much as possible) the inspection image.

[0115] The method of FIG. **8** includes (operation **810**) removing, or at least reducing, noise present in the inspection image. This can include using filter(s) to remove noise, such as media filters, wavelet filters, etc. Operation **810** is a denoising operation. This denoising operation can include using the dimension(s) of the design elements, and in particular the critical dimensions(s) (CD) of the design elements, determined using e.g., the method of FIG. **2**. In some examples, the minimum of the computed CD and distance between the design elements can be used to design a low pass filter for noise reduction. The inspection images suffer from charging and non-uniform intensity variations. Depending on the field of view, a high pass filter can be designed to eliminate these low frequency noises.

[0116] The method of FIG. **8** can also include (operation **820**) enhancing the edges of the structural elements of the inspection image. Operation **820** can be performed on the denoised inspection image (after operation **810**). In particular, the pixel intensity of the edges of the structural elements can be increased, such as increasing the brilliance/luminosity of the edges. In some examples, selective Gamma correction can be performed on the edges. In some examples, enhancing the edges of the design elements can include using the dimension(s) of the design elements, and in particular the critical dimensions(s) (CD) of the design elements, determined using e.g., the method of FIG. **2**. According to some examples, a Morphological Top Hat transform along eight equally spaced directions restores the brilliance of the edges of the structural elements. The structuring element used for the morphological operations can be determined based on the CD of the design elements.

[0117] The method of FIG. **8** can also include (operation **830**) segmenting the inspection image. Operation **830** can be performed on the inspection image after it has been processed according to operations **810** and **820**. In some examples, distance transform is applied on the segmented inspection image.

[0118] In some examples, segmentation of the inspection image is performed only when the design image (to be registered with the inspection image) is informative of a single layer, but is not performed when the design image is informative of a plurality of layers.

[0119] Attention is now drawn to FIG. **9**A and FIG. **9**B.

[0120] The method of FIG. **9**A attempts to find a translation (or shift) enabling registering the design image with the inspection image. To this end, the method of FIG. **9**A includes using (operation **900**) a registration algorithm to obtain a first estimate of a shift, enabling registration between the design image and the inspection image. The registration algorithm can receive the design image after it has been processed with the various methods described above (see FIG. **2**, FIG. **6**A and FIG. **7**), and the inspection image after it has been processed as described above (see FIG. **8**). The registration algorithm can process the design image and the inspection image, as explained hereinafter.

[0121] In some examples, operation **900** includes repeatedly shifting the design image **920** relative to the inspection image value **930** (or conversely) by a shift value **950**, and, for each relative shift, computing data informative of a match between the design image **920** and the inspection image **930**.

[0122] In other words, a correspondence between the design image and the inspection image, for different successive positions of the design image relative to the inspection image (note that this includes moving the design image and/or the inspection image to obtain different relative positions), is computed. Each position of these successive positions differs from a previous position by a given shift **950**. Note that the relative shift between the design image and the inspection image (in order to find the best match) can be performed, both along the horizontal axis and the vertical axis.

[0123] In some examples, for each relative shift (relative position between the design image and the inspection image), mutual information (see e.g. https://en.wikipedia.org/wiki/Mutual_information) is computed between the design image **920** and the inspection image **930**. The mutual information indicates the level of correspondence between the design image **920** and the inspection image **930**. The relative shift (relative position) for which the correspondence (e.g., mutual information) indicates the best match, corresponds to a first estimate of the shift, enabling a registration of the design image with the inspection image.

[0124] In some examples, the shift value (see **950**), used by the registration algorithm to test different relative positions between the design image and the inspection image, is selected in an interval between the smallest critical dimension (smallest CD) among the design elements of the design image, and half the periodic distance (also called pitch distance) between similar design elements of the design image. Note that the smallest CD and the pitch distance may have been computed using the method of FIG. **2**.

[0125] In some examples, the shift value used by the registration algorithm to test different relative positions between the design image and the inspection image, can be different along the horizontal axis than from the vertical axis.

[0126] In some examples, the first estimate of the shift between the design image and the inspection image can be fine-tuned (operation **910**), in order to improve the correspondence between the design image and the inspection image. In particular, at operation **910**, the relative shift **951** (between the design image and the inspection image) can be selected to be smaller than the shift **950** used at operation **900**. In some examples, the relative shift **951** can correspond to a pixel or sub-pixel shift (this is not limitative).

[0127] Operation **910** enables obtaining an optimal shift, which corresponds to the translation required to make (as much as possible) the design image match the inspection image. Operation **910** can include using a gradient descent algorithm (such as a stochastic gradient descent algorithm) to determine the optimal shift.

[0128] The design image can be displaced according to the optimal shift, and then the registration process can be further pursued, as explained hereinafter.

[0129] Attention is now drawn to FIG. **10**A.

[0130] Once the optimal shift has been determined (as explained, e.g., with reference to FIG. **9**A), the registration process can include determining (operation **1000**) a deformation of the design image (or of each of the design layers) in order to match the inspection image according to a matching criterion. The matching criterion can define a level of match that is required, or can indicate that the deformed design elements must match the inspection image as much as possible. Note that the deformation can correspond to an expansion of the elements of the design image, or to a shrink of the elements of the design image.

[0131] The deformation can include dilating the elements of the design image along a horizontal axis (X axis) of the design image according to a first deformation factor F_X and dilating the elements of the design image along a vertical axis (Y axis) of the design image according to a second deformation factor F_Y (which can be different from the first deformation factor F_X). Note that the same first deformation factor F_X can be applied to all design elements along the horizontal axis, and the same second deformation factor F_Y can be applied to all design elements along the vertical axis.

[0132] The method of FIG. **10**A can include, for each candidate deformation factor, computing data informative of a match between the design image and the inspection image. In some examples, this data corresponds to mutual information. Several values of the candidate deformation factor can be tested, until an optimal deformation factor (for which the mutual information, or other correlation value, indicate the best match) is found (operation **1010**). In some examples, a user provides a first estimate of the deformation factor, and the algorithm tests several values around this first estimate, in order to obtain an optimal deformation factor (along the horizontal axis and along the vertical axis). Indeed, the user generally knows the range of process window (range of possible errors in the process), which can be used as a starting point to find the optimal deformation factor.

[0133] A non-limitative example of FIG. **10**A is illustrated in FIGS. **10**B and **10**C, in which the design elements **1030**, **1040**, and **1050** are expanded into the design elements $\mathbf{1030}_1$, $\mathbf{1040}_1$, and $\mathbf{1050}_1$, in order to better match the structural elements **1060**, **1070**, and **1080**.

[0134] Attention is now drawn to FIGS. **11**A and **11**B.

[0135] Once the design image has been processed as explained above (shift applied to the design image and deformation applied to the design image), it can be processed, as explained with reference to FIG. **11**A.

[0136] The method of FIG. **11**A includes determining (operation **1100**) a grid **1160** of points in the design image. According to some examples, this grid **1160** of points is such that the distance **1150** between the points of the grid is equal to or larger than half the minimum distance between design elements in the design image. As explained with reference to operation **202** in FIG. **2**, the distance between the various adjacent design elements can be computed. The minimum value of this distance can be used to determine the minimum distance between the points of the grid.

[0137] The distance between the points of the grid along the horizontal axis is generally selected as constant, but this is not limitative. Similarly, the distance between the points of the grid along the vertical axis is generally selected as constant, but this is not limitative. The distance between the points of the grid along the horizontal axis is not necessarily equal to the distance between the points of the grid along the vertical axis.

[0138] The maximal value of the distance between the points of the grid can be selected to obtain a sufficient number of points along the horizontal axis and along the vertical axis. In some examples, the sufficient number of points corresponds to three points along the horizontal axis and three points along the vertical axis. This is however not limitative.

[0139] The method of FIG. **11**A further includes determining (operation **1110**) a displacement (designated as displacement parameters) of one or more points of the grid of the design image, in order to match the inspection image according to a matching criterion. The matching criterion can define a level of match that is required, or can indicate that the points (after their displacement) must match the inspection image as much as possible. Note that each point can be displaced with a different displacement. The displacement parameters can include, for each point, the displacement required along the horizontal axis and the displacement required along the vertical axis. A non-limitative example is illustrated in FIG. **11**B, in which three points **1170**, **1171**, and **1172** of the grid **1160** of points have been displaced.

[0140] In some examples, operation **1110** corresponds to a deformable registration. In some examples, the method described in Rueckert et al., "*Nonrigid registration using free-form deformations: application to breast MR images*", IEEE Journals & Magazine, IEEE Xplore, can be used at operation **1110**.

[0141] Once the displacement parameters of each point of the grid have been determined, the values of the displacement parameters of the other points of the design image (which do not belong to the grid and are located between the points of the grid) can be determined by using an interpolation method. The method of FIG. **11**A further includes applying (operation **1120**) the displacement parameters to the points of the design image, to transform the design image. In some examples, the method of FIG. **11**A can be performed for each design layer independently. A grid of points is defined for each design layer, and displacement parameters are computed for each point of the grid. Each design layer is then transformed using the displacement parameters.

[0142] It has been mentioned above (see operation **204** in FIG. **2**) that the presence of one or more horizontal lines and/or vertical lines in the design image or in the design data can be determined. This information can be used to define the grid of points **1160**. Indeed, if a horizontal line or a vertical line is present, it is not necessary to place a lot of points of the grid along it.

[0143] In some examples, the shift, deformation, and displacement parameters which have been determined can be output using an output device (such as a screen).

[0144] Attention is now drawn to FIGS. **12**A and **12**B.

[0145] In some examples, the design image results from the fusion of a plurality of design layers (CAD layers after rasterization). This is visible in FIG. **12**B which illustrates three design layers **1250**, **1251**, and **1252**. Each design layer includes its own design elements.

[0146] Once the shift required for the design image (X axis, Y axis) has been determined (as explained with reference to FIG. **9**A), the deformation required for the design image (X axis, Y axis) has been determined (as explained with reference to FIG. **10**A), and displacement parameters have been determined for points of the design image (as explained with reference to FIG. **11**A), it is possible to apply (operation **1210**) the shift, deformation, and displacement parameters to each design layer (see layers **1250**, **1251**, and **1252**) separately. Then, a new design image can be recomputed, by fusing the different modified design layers.

[0147] Attention is now drawn to FIG. **13**, which describes an iterative process of registration between a design image or design (informative of a plurality of design layers) and an inspection image.

[0148] Operation **1300** includes determining the shift required for the design image (X axis, Y axis, as explained with reference to FIG. **9**A), determining the deformation required for the design image (X axis, Y axis, as explained with reference to FIG. **10**A), and determining displacement parameters for points of the design image (as explained with reference to FIG. **11**A).

[0149] The method of FIG. **13** further includes applying (operation **1310**) the shift, deformation, and displacement parameters to the design image, or to each design layer separately.

[0150] The process can be repeated iteratively, for each design layer separately. This is shown at operation **1320**. For each given design layer, the method includes determining the shift required for the given design layer (X axis, Y axis, as explained with reference to FIG. **9**A). Note that since a first estimate of the required shift for the design image has already been determined at operation **1300**, it is sufficient to perform a search for the optimal shift of each given design layer on a small scale, such as at pixel level. In other words, it is sufficient to perform, for each given design layer, operation **910** of FIG. **9**A (fine tuning of the shift), without being required to perform operation **900** (global estimate of the shift). At operation **1320**, the method further includes, for each given design layer, determining the deformation required for the given design layer (X axis, Y axis, as explained with reference to FIG. **10**A). At operation **1320**, the method further includes, for each given design layer, defining a grid of points in the design layer and determining displacement parameters for points of the grid of the design layer (as explained with reference to FIG. **11**A). In other words, registration data (including translation data, deformation data, and displacement parameters of various points) between each design layer and the inspection image can be obtained.

[0151] The registration data can be used for various purposes, such as (but not limited to), determining overlay information of the specimen present in the inspection image.

[0152] In the detailed description, numerous specific details have been set forth in order to provide a thorough understanding of the disclosure. However, it will be understood by those skilled in the art that the presently disclosed subject matter may be practiced without these specific details. In other instances, well-known methods, procedures, components and circuits have not been described in detail so as not to obscure the presently disclosed subject matter.

[0153] Unless specifically stated otherwise, as apparent from the aforementioned discussions, it is appreciated that throughout the specification discussions utilizing terms such as "obtaining", "applying", "determining", "performing", "using", "increasing", "reducing", "estimating", or the like, refer to the action(s) and/or process(es) of a computer that manipulate and/or transform data into other data, said data represented as physical, such as electronic, quantities and/or said data representing the physical objects.

[0154] The terms "computer" or "computer-based system" should be expansively construed to include any kind of hardware-based electronic device with a data processing circuitry (e.g., digital signal processor (DSP), a GPU, a TPU, a field programmable gate array (FPGA), an application specific integrated circuit (ASIC), microcontroller, microprocessor etc.), including, by way of non-limiting example, the computer-based system **103** of FIG. **1** and respective parts thereof disclosed in the present application. The data processing circuitry (designated also as processing circuitry—see e.g., processing circuitry **104**) can comprise, for example, one or more processors operatively connected to computer memory, loaded with executable instructions for executing operations, as further described below. The data processing circuitry encompasses a single processor or multiple processors, which may be located in the same geographical zone, or may, at least partially, be located in different zones, and may be able to communicate together. The one or more processors can represent one or more general-purpose processing devices such as a microprocessor, a central processing unit, or the like. More particularly, a given processor may be one of: a complex instruction set computing (CISC) microprocessor, a reduced instruction set computing (RISC) microprocessor, a very long instruction word (VLIW) microprocessor, a processor implementing other instruction sets, or a processor implementing a combination of instruction sets. The one or more processors may also be one or more special-purpose processing devices, such as an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), a digital signal processor (DSP), a network processor, or the like. The one or more processors are configured to execute instructions for performing the operations and steps discussed herein.

[0155] The memories referred to herein can comprise one or more of the following: internal memory, such as, e.g., processor registers and cache, etc., main memory such as, e.g., read-only memory (ROM), flash memory, dynamic random access memory (DRAM) such as synchronous DRAM (SDRAM) or Rambus DRAM (RDRAM), etc.

[0156] The terms "non-transitory memory" and "non-transitory storage medium" used herein should be expansively construed to cover any volatile or non-volatile computer memory suitable to the presently disclosed subject matter. The terms should be taken to include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) that store the one or more sets of instructions. The terms shall also be taken to include any medium that is capable of storing or encoding a set of instructions for execution by the computer and that cause the computer to perform any one or more of the methodologies of the present disclosure. The terms shall accordingly be taken to include, but not be limited to, a read only memory ("ROM"), random access memory ("RAM"), magnetic disk storage media, optical storage media, flash memory devices, etc.

[0157] It is to be noted that while the present disclosure refers to the processing circuitry **104** being configured to perform various functionalities and/or operations, the functionalities/operations can be performed by the one or more processors of the processing circuitry **104** in various ways. By way of example, the operations described hereinafter can be performed by a specific processor, or by a combination of processors. The operations described hereinafter can thus be performed by respective processors (or processor combinations) in the processing circuitry **104**, while, optionally, at least some of these operations may be performed by the same processor. The present disclosure should not be limited to be construed as one single processor always performing all the operations.

[0158] The term "specimen" used in this specification should be expansively construed to cover any kind of wafer, masks, and other structures, combinations and/or parts thereof used for manufacturing semiconductor integrated circuits, magnetic heads, flat panel displays, and other semiconductor-fabricated articles.

[0159] The term "examination" used in this specification should be expansively construed to cover any kind of metrology-related operations, as well as operations related to detection and/or classification of defects in a specimen during its fabrication. Examination is provided by using non-destructive examination tools during or after manufacture of the specimen to be examined. By way of non-limiting example, the examination process can include runtime scanning (in a single or in multiple scans), sampling, reviewing, measuring, classifying, and/or other operations provided with regard to the specimen or parts thereof, using the same or different inspection tools. Likewise, examination can be provided prior to manufacture of the specimen to be examined, and can include, for example, generating an examination recipe(s) and/or other setup operations. It is noted that, unless specifically stated otherwise, the term "examination", or its derivatives used in this specification, is not limited with respect to resolution or size of an inspection area. A variety of non-destructive examination tools includes, by way of non-limiting example, scanning electron microscopes, atomic force microscopes, optical inspection tools, etc.

[0160] By way of non-limiting example, run-time examination can employ a two-phase procedure, e.g., inspection of a specimen followed by review of sampled locations of potential defects. During the first phase, the surface of a specimen is inspected at high-speed and relatively low-resolution. In the first phase, a defect map is produced to show suspected locations on the specimen having high probability of a defect. During the second phase, at least some of the suspected locations are more thoroughly analyzed with relatively high resolution. In some cases, both phases can be implemented by the same inspection tool, and, in some other cases, these two phases are implemented by different inspection tools.

[0161] The term "defect" used in this specification should be expansively construed to cover any kind of abnormality or undesirable feature formed on or within a specimen.

[0162] The term "design data" used in the specification should be expansively construed to cover any data indicative of hierarchical physical design (layout) of a specimen. Design data can be provided by a respective designer and/or can be derived from the physical design (e.g., through complex simulation, simple geometric and Boolean operations, etc.). Design data can be provided in different formats such as, by way of non-limiting examples, GDSII format, OASIS format, etc. Design data can be presented in vector format, grayscale intensity image format, or otherwise.

[0163] It is appreciated that, unless specifically stated otherwise, certain features of the presently disclosed subject matter, which are described in the context of separate embodiments, can also be provided in combination in a single embodiment. Conversely, various features of the presently disclosed subject matter, which are described in the context of a single embodiment, can also be provided separately or in any suitable sub-combination. In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the methods and apparatus.

[0164] In embodiments of the presently disclosed subject matter, fewer, more, and/or different stages than those shown in the methods of in FIGS. **2**, **6**A, **7**, **8**, **9**A, **10**A, **11**A, **12**A and **13** may be executed. In embodiments of the presently disclosed subject matter, one or more stages illustrated in the methods of in FIGS. **2**, **6**A, **7**, **8**, **9**A, **10**A, **11**A, **12**A, and **13** may be executed in a different order, and/or one or more groups of stages may be executed simultaneously.

[0165] It is to be understood that the invention is not limited in its application to the details set forth in the description contained herein or illustrated in the drawings.

[0166] It will also be understood that the system according to the invention may be, at least partly, implemented on a suitably programmed computer. Likewise, the invention contemplates a computer program being readable by a computer for executing the method of the invention. The invention further contemplates a non-transitory computer-readable memory tangibly embodying a program of instructions executable by the computer for executing the method of the invention.

[0167] The invention is capable of other embodiments and of being practiced and carried out in various ways. Hence, 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. As such, those skilled in the art will appreciate that the conception upon which this disclosure is based may readily be utilized as a basis for designing other structures, methods, and systems for carrying out the several purposes of the presently disclosed subject matter.

[0168] Those skilled in the art will readily appreciate that various modifications and changes can be applied to the embodiments of the invention as hereinbefore described without departing from its scope, defined in and by the appended claims.

What is claimed is:

1. A system comprising one or more processing circuitries configured to:
obtain
an inspection image of a semiconductor specimen, and
a design image or design data, informative of a plurality of design elements,
determine data D_{pitch} informative of a periodic distance between design elements of the plurality of design elements, which are associated with a shape meeting a similarity criterion, and
use the data D_{pitch} to obtain registration data between the design image or the design data, and the inspection image.

2. The system of claim **1**, wherein the design image or the design data are informative of a plurality of design layers, wherein the system is configured to determine, for each given design layer of the plurality of design layers, given registration data between the given design layer and the inspection image.

3. The system of claim **1**, configured to determine a derivative signal corresponding to a derivative of a pixel intensity signal associated with the design image or with the design data, and to use the derivative signal to determine data D_{pitch}.

4. The system of claim **1**, configured to determine a correspondence between the design image and the inspection image, for different shifts of the design image relative to the inspection image, wherein amplitude of the different shifts has been determined based on data D_{pitch}.

5. The system of claim **4**, wherein determining a correspondence between the design image and the inspection image comprises determining mutual information between the design image and the inspection image.

6. The system of claim **1**, configured to determine a correspondence between the design image and the inspection image, for different successive positions of the design image relative to the inspection image, wherein each position of these successive positions differs from a previous position by a shift which is equal to or smaller than half said periodic distance.

7. The system of claim **1**, configured to:
determine a correspondence between the design image and the inspection image, for different first successive positions of the design image relative to the inspection image, wherein each position of these first successive positions differs from a previous position by a first shift value, to obtain a first estimate of a registered position of the design image with respect to the inspection image, and
determine a correspondence between the design image and the inspection image, for different second successive positions of the design image relative to the inspection image, located around said first estimate of the registered position, wherein each position of these second successive positions differs from a previous position by a second shift value, smaller than the first shift value, to obtain a second estimate of a registered position of the design image with respect to the inspection image.

8. The system of claim **1**, wherein, for at least one given design element of the design elements, the system is configured to convert edges of the given design element into rounded edges, wherein a curvature of the rounded edges is selected based on one or more dimensions of the given design element.

9. The system of claim **1**, wherein the inspection image comprises a plurality of structural elements, wherein the system is configured to perform at least one of (i) or (ii):
(i) perform a reduction of noise present in the inspection image, wherein said reduction depends on one or more dimensions of the structural elements, or
(ii) perform an enhancing of edges of one or more of the structural elements, wherein said enhancing depends on one or more dimensions of the structural elements.

10. The system of claim **1**, configured to detect presence of one or more horizontal or vertical lines in the design image or in the design data, and use this detection to determine the registration data between the design image or the design data and the inspection image.

11. The system of claim **1**, wherein the registration data comprise:
data informative of a shift of the design image or of the design data;
data informative of a deformation of one or more of the plurality of design elements; and
displacement parameters of one or more points of the design image or of the design data.

12. The system of claim **1**, configured to determine a deformation enabling a match between the design elements and structural elements of the inspection image according to a matching criterion.

13. The system of claim **1**, configured to:
determine a grid of points in the design image,
determine displacement parameters of a plurality of points of the grid, in order to match the inspection image according to a matching criterion,
wherein at least two points of the grid are associated with different displacement parameters, and
use the displacement parameters to transform the design image or the design data.

14. The system of claim **13**, wherein a distance between adjacent points of the grid is equal to or larger than half a minimum distance between the design elements.

15. The system of claim **1**, wherein:
the design image or the design data is informative of a plurality of design layers,
the registration parameters are informative of at least one of:
a shift,
a deformation, or
displacement parameters of one or more points of the design image,
wherein the system is configured to use said registration parameters to transform each design layer separately.

16. The system of claim **1**, wherein the design data is informative of a plurality of design layers, wherein the system is configured to rasterize the design data of the plurality of design layers, and combine them to obtain the design image, without requiring user input for defining pixel intensity in the design image.

17. A system comprising one or more processing circuitries configured to:

obtain

an inspection image of a semiconductor specimen, and

a design image or design data, informative of a plurality of design layers, each including one or more design elements,

determine registration parameters between the design image or the design data and the inspection image, wherein the registration parameters are informative of at least one of:

a shift,

a deformation, or

displacement parameters of one or more points of the design image or of the design data, and

use the registration parameters to transform, separately, each design layer of the plurality of design layers.

18. The system of claim **17**, configured to, for each given design layer of the plurality of the design layers, after said transformation:

determine updated registration parameters between the given design layer and the inspection image, wherein the updated registration parameters are informative of:

a shift,

a deformation, and

displacement parameters of one or more points of the given design layer.

19. The system of claim **17**, configured to:

determine a grid of points in the design image or in the design data,

determine displacement parameters of one or more points of the grid, in order to match the inspection image according to a matching criterion, wherein at least two points are assigned with different displacement parameters.

20. A non-transitory computer readable medium comprising instructions that, when executed by one or more processing circuitries, cause the one or more processing circuitries to perform:

obtaining

an inspection image of a semiconductor specimen, and

a design image or design data, informative of a plurality of design elements,

determining data D_{pitch} informative of a periodic distance between design elements of the plurality of design elements, which are associated with a shape meeting a similarity criterion, and

using the data D_{pitch} to obtain registration data between the design image or the design data, and the inspection image.

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