(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
16 August 2018 (16.08.2018)

(10) International Publication Number
WO 2018/147938 A1

(51) International Patent Classification:
G03F 7/20 (2006.01) ***H01L 21/66*** (2006.01)

(21) International Application Number:
PCT/US2017/066853

(22) International Filing Date:
15 December 2017 (15.12.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/457,787 10 February 2017 (10.02.2017) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,

(54) Title: MITIGATION OF INACCURACIES RELATED TO GRATING ASYMMETRIES IN SCATTEROMETRY MEASUREMENTS

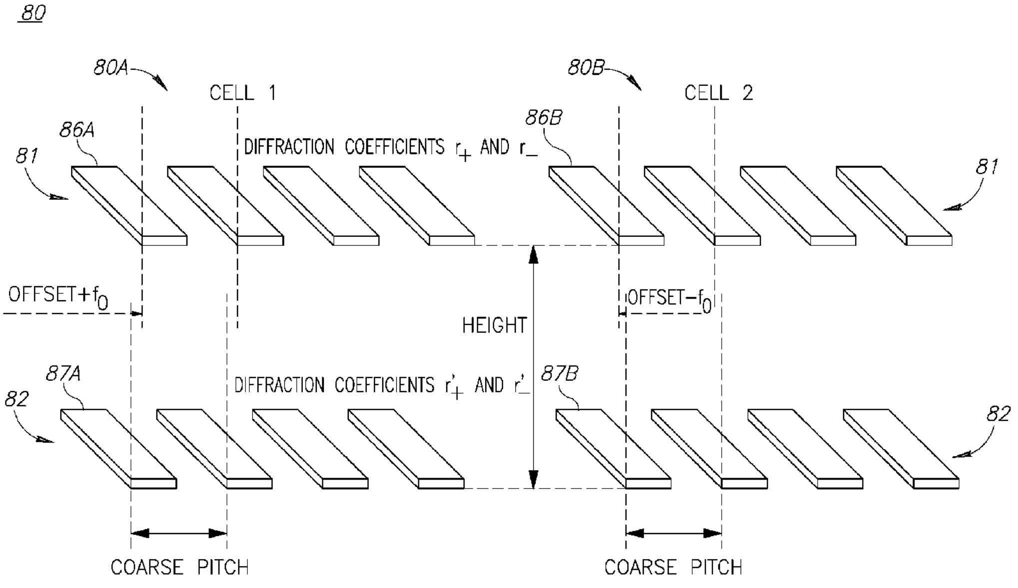

Figure 1

(57) Abstract: Scatterometry overlay targets as well as target design and measurement methods are provided, which mitigate the effects of grating asymmetries in diffraction based overlay measurements. Targets comprise additional cells with sub-resolved structures replacing resolved coarse pitch gratings and/or comprise alternating sub-resolved structures with coarse pitch periodicity - to isolate and remove inaccuracies that result from grating asymmetries. Measurement methods utilize orthogonally polarized illumination to isolate the grating asymmetry effects in different measurement directions, with respect to the designed target structures.

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UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

MITIGATION OF INACCURACIES RELATED TO GRATING ASYMMETRIES IN SCATTEROMETRY MEASUREMENTS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 62/457,787 filed on February 10, 2017, which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

1. TECHNICAL FIELD

[0002] The present invention relates to the field of metrology, and more particularly, to scatterometry overlay targets and measurement methods therefor.

2. DISCUSSION OF RELATED ART

[0003] Current diffraction-based overlay (DBO) marks, or targets, are composed of cells having two gratings, one grating in each layer, which are to be aligned. The diffracted signals from these cells are used to compute the displacement (the overlay) between the two layers. Measured asymmetries in the aforementioned cells are used to estimate the displacement of one grating with respect to the other.

SUMMARY OF THE INVENTION

[0004] The following is a simplified summary providing an initial understanding of the invention. The summary does not necessarily identify key elements nor limits the scope of the invention, but merely serves as an introduction to the following description.

[0005] One aspect of the present invention provides SCOL (scatterometry overlay) targets comprising, along at least one measurement direction: two cells having periodic structures with a specified coarse pitch at least at two wafer layers, wherein the two cells have opposite offsets of a top periodic structure with respect to a bottom periodic structure in the respective layers, and two cells having, each, a periodic structure with the specified coarse pitch at a different one of the two layers and a sub-resolved periodic structure at the other one of the two layers.

[0006] 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

[0007] 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.

[0008] In the accompanying drawings:

[0009] **Figure 1** is a high-level schematic illustration of a scatterometry target with grating asymmetries, presenting sections of two cells of the target, according to some embodiments of the invention.

[0010] **Figure 2A** is a high-level schematic illustration of metrology targets, their derivation from prior art targets, and measurement configurations, according to some embodiments of the invention.

[0011] **Figure 2B** is a high-level schematic illustration of an additional pair of cells in the metrology targets, according to some embodiments of the invention.

[0012] **Figure 3** is a high-level schematic illustration of metrology targets, according to some embodiments of the invention.

[0013] **Figure 4** is a high-level schematic illustration of a metrology measurement setting, according to some embodiments of the invention.

[0014] **Figure 5** is a high-level flowchart illustrating a method, according to some embodiments of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0015] 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.

[0016] 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.

[0017] 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.

[0018] Embodiments of the present invention provide efficient and economical methods and mechanism for mitigating the effects of grating asymmetries in DBO (diffraction based overlay) measurements and thereby provide improvements to the technological field of overlay scatterometry metrology. Improved overlay target designs and measurement techniques are provided, which to mitigate the effect of target grating asymmetries. Grating asymmetries arise due to the nature of the manufacturing process, and are unaccounted for by current methods which assume that the asymmetries originate strictly from the displacement between the layers (overlay plus intended offsets), and consequentially, any additional asymmetry in the grating is wrongly interpreted in the prior art as an additional displacement, leading to an inaccurate measurement of the overlay. The inventors have found out ways to characterize and prevent overlay estimation inaccuracies which are due to grating asymmetries.

[0019] Scatterometry overlay targets as well as target design and measurement methods are provided, which mitigate the effects of grating asymmetries in diffraction based overlay measurements. Targets comprise additional cells with sub-resolved structures replacing resolved coarse pitch gratings and/or comprise alternating sub-resolved structures with coarse pitch periodicity - to isolate and remove inaccuracies that result from grating asymmetries. Measurement methods utilize orthogonally polarized illumination to isolate the grating asymmetry effects in different measurement directions, with respect to the designed target structures.

[0020] **Figure 1** is a high-level schematic illustration of scatterometry target **80** with grating asymmetries, presenting sections of two cells **80A**, **80B** of target **80**, according to some embodiments of the invention.

[0021] Illustrated grating-over-grating system **80** comprises periodic structures **86A**, **87A**, **86B**, **87B** in at least two layers **81**, **82** of corresponding target cells **80A**, **80B**. Periodic structures in each cell are displaced by $\Delta = \text{offset} + \text{overlay}$ relative to each other, the displacement comprising intended offsets which are opposite between cells **80A**, **80B** (indicated in **Figure 1** as $\pm f_0$) and the overlays which are to be measured by the metrology measurements (not shown explicitly in **Figure 1**). Gratings **86A**, **86B** and **87A**, **87B** in layers **81** and **82**, respectively, are separate by a height indicated as h. In the presence of grating asymmetries in the top and/or the bottom gratings, the diffraction coefficients of the +1 and -1 orders of the measured metrology signals are not equal. Denoting the diffraction coefficients of the +1 and -1 orders of the top grating as r_+ and r_-, respectively, and those of the bottom grating r'_+ and r'_-. Because of grating asymmetries, the diffraction coefficients may differ in both amplitude and phase, and are therefore expressed in the form $r_{\pm 1} = (\rho \pm \delta\rho)e^{i(\psi \pm \delta\psi)}$ for the top grating and $r'_{\pm 1} = (\rho' \pm \delta\rho')e^{i(\psi' \pm \delta\psi')}$ for the bottom grating. **Equations 1** present the intensity of the +1 and -1 diffraction order signals in the presence of a grating asymmetry, neglecting multiple scattering effects. The expression $\phi_{\mathrm{m}}(x,y)$ provides the leading order for the phase accrued by the m^{th}order due to the optical path difference between the two gratings.

$$I_{+1}(x,y) = |E_0|^2 \begin{bmatrix} (\rho+\delta\rho)^2 + (\rho'+\delta\rho')^2 + 2(\rho+\delta\rho)(\rho'+\delta\rho') \times \\ \times \cos\left(\psi - \psi' + \delta\psi - \delta\psi' - \phi_0(x,y) - \phi_{+1}(x,y) + \frac{2\pi\Delta}{P}\right) \end{bmatrix}$$

$$I_{-1}(-x,-y) = |E_0|^2 \begin{bmatrix} (\rho-\delta\rho)^2 + (\rho'-\delta\rho')^2 + 2(\rho-\delta\rho)(\rho'-\delta\rho') \times \\ \times \cos\left(\psi - \psi' - \delta\psi + \delta\psi' - \phi_0(x,y) - \phi_{+1}(x,y) - \frac{2\pi\Delta}{P}\right) \end{bmatrix}$$

$$\phi_{\mathrm{m}}(x,y) = \frac{2\pi h}{\lambda}\sqrt{n^2 - \left(x + \frac{m\lambda}{P}\right)^2 - y^2}$$

Equations 1

[0022] Equation 2 expresses the differential signal $D(x,y) = I_{+1}(x,y) - I_{-1}(-x,-y)$, with the phase defined as $\Phi(x,y) = \psi - \psi' - \phi_0(x,y) - \phi_{+1}(x,y)$.

$$\begin{aligned} D(x,y) = 4|E_0|^2 \Big[& \rho\delta\rho + \rho'\delta\rho' \\ & - 2(\rho\rho' + \delta\rho\delta\rho')\sin\Phi(x,y)\sin\left(\frac{2\pi\Delta}{P} + \delta\psi - \delta\psi'\right) \\ & + 2(\rho\delta\rho' + \rho'\delta\rho)\cos\Phi(x,y)\cos\left(\frac{2\pi\Delta}{P} + \delta\psi - \delta\psi'\right)\Big] \end{aligned}$$

Equation 2

[0023] Equation 3 provides an approximation for the differential signal of **Equation 2** under the following assumptions: (i) The contribution of the phase perturbations $\delta\psi - \delta\psi'$ to the overlay accuracy budget is negligible as it is much smaller than the contribution of the amplitude perturbation described by $\delta\rho$ *and* $\delta\rho'$, as the phase perturbations are within the geometrical ambiguity range which corresponds to the uncertainty in definition of center of symmetry for slightly asymmetric target; (ii) The measurement conditions (wavelength, polarization as an example) may be chosen to make the phase $\Phi(x,y)$ close to $\pi/2 \pm \pi n$, with integer n – to minimize the term $2(\rho\delta\rho' + \rho'\delta\rho)\cos\Phi(x,y)\cos\left(\frac{2\pi\Delta}{P} + \delta\psi - \delta\psi'\right)$, depending on $\cos\Phi(x,y)$, to negligible size and approximating $\sin\Phi(x,y)$ as 1; and (iii) Approximating the differential signal to the leading order (neglecting the terms in the order of magnitude of $\Theta(\delta\rho\delta\rho')$).

$$D(x,y) = 4\,|E_0|^2\,[\rho\delta\rho + \rho'\delta\rho' - 2\rho\rho'\sin(\frac{2\pi\Delta}{P})] \qquad \textbf{Equation 3}$$

[0024] **Equation 3** demonstrates that the differential signal deviates from the ideal signal assumed by prior art overlay measurement algorithms, and introduces an additional inaccuracy into the overlay estimations. The inventors point out that in **Equation 3**, the term $2\rho\rho'\sin\left(\frac{2\pi\Delta}{P}\right)$ provides a basis for the overlay measurement through the estimation of Δ, while the terms $\rho\delta\rho + \rho'\delta\rho'$provide an estimation for the overlay measurement inaccuracy due, e.g., to grating asymmetries. In the following, the inventors present ways to take into account the grating asymmetries which remain unaccounted for in the prior art.

[0025] **Figure 2A** is a high-level schematic illustration of metrology targets **100**, their derivation from prior art targets **90**, and measurement configurations, according to some embodiments of the invention. The following solutions handle the inaccuracies introduced e.g., by grating asymmetries, which were derived above and presented in **Equation 3**. Prior art targets **90** are represented schematically as having two cells in each measurements direction, cells **91** in measurement direction X and cells **92** in measurement direction Y, with each pair of cells designed according to the principles described in **Figure 1** for cells **80A**, **80B** having periodic structures with opposite designed offsets between the layers in each cell.

[0026] In certain embodiments, disclosed targets **100** comprise cell pairs **101**, **102** in respective X and Y measurement directions designed as in prior art targets **90** – and additional two pairs **111** and **112**, with cells **111A**, **111B** and **112A**, **112B** in each measurement direction X and Y respectively (the addition is indicated by arrow **210**, see **Figure 5** below).

[0027] **Figure 2B** is a high-level schematic illustration of additional pair **111** of cells in metrology targets **100**, according to some embodiments of the invention. In each pair **111** of cells, in one cell (e.g., **111A** in the X direction) the top grating is replaced by an appropriately designed sub-resolved grating **116A**; and in the other cell (e.g., **111B** in the X direction), the bottom structure is replaced by a different appropriately designed sub-resolved structure **117B**. Measurements of these two cells allow the correction of inaccuracies due to asymmetries in the grating in the following way. To the leading order the signal returning from a grating-over-grating is given by the single-scattering model, i.e. by the interference of the light diffracted from top grating with the light diffracted from the bottom grating. It can be shown that the differential signal of cell **111A** with only bottom grating **117A** is $D(x,y) = 4|E_0|^2\rho'\delta\rho'$ and that the differential signal of cell **111B** with only top grating **116B** is $D(x,y) = 4|E_0|^2\rho\delta\rho$. Therefore, the additional cells provide an estimation of the inaccuracies resulting from grating asymmetry independently from the measurements of cells **101** of target **100**. Subtracting the inaccuracy estimations from cells **111** from the non-ideal differential signal derived from cells **101** therefore removes the first and second terms $\rho\delta\rho + \rho'\delta\rho'$of **Equation 3**, which deviate from the signal in the absence of asymmetries. The third term $2\rho\rho'\sin\left(\frac{2\pi\Delta}{P}\right)$can then be minimized by picking a wavelength far from a resonance, leaving a signal close to the ideal one assumed by the algorithm. Similar cells **112** (**112A**, **112B**, corresponding to **111A**, **111B**, in the Y measurement direction) and measurements may be applied to the Y measurement direction as well, with respect to measurements of cells **102**.

[0028] As illustrated schematically in **Figure 2B**, sub-resolved gratings **116A**, **117B** in cells **111A**, **111B**, respectively, comprise periodic structure(s) with sub-resolved pitches, e.g., pitch below 300nm, 200nm or below 100nm (as non-limiting example for typical device pitches). Sub-resolved gratings **116A**, **117B** may be configured to maintain the optical properties of the stack in cells **111** and **112** identical, similar, or with a controlled difference with respect to cells **101**, **102** having periodic structures with coarse, resolved pitches (e.g., above 500nm) both layers **81**, **82**. Sub-resolved structures **116A**, **117B** may be configured to replace gratings **86A**, **87B** (see **Figure 1**) with respect to the optical properties of the stack. For example, using illumination radiation which is polarized parallel to the target lines (the elements of periodic structures **117A**, **116B**), sub-resolved periodic structures **116A**, **117B** may be configured to have the same filling factor as the original target periodic elements **86A**, **87B** – to provide the same effective permittivity for cells **111**, **112** as for cells **101**, **102**, namely $\varepsilon_{eff} = \varepsilon_1 \cdot \eta + \varepsilon_2 \cdot (1-\eta)$, with ε_1 denoting the grating material permittivity, ε_2 denoting the surrounding material permittivity and η

denoting the filling factor. In the case of electric field directed perpendicular to the grating lines, the effective medium approximation is $\varepsilon_{eff} = \frac{\varepsilon_1 \cdot \varepsilon_2}{\varepsilon_1 \cdot (1-\eta_1) + \varepsilon_2 \cdot \eta_1}$ so that the corresponding filling factor (η_1) for grating(s) **116A**, **117B** replacing the original target gratings **86A**, **87B**, respectively, should satisfy the condition:

$$\frac{\varepsilon_1 \cdot \varepsilon_2}{\varepsilon_1 \cdot (1-\eta_1) + \varepsilon_2 \cdot \eta_1} = \varepsilon_1 \cdot \eta + \varepsilon_2 \cdot (1-\eta) \Rightarrow \eta_1 = \eta \frac{\varepsilon_1}{\varepsilon_1 \cdot \eta + \varepsilon_2 \cdot (1-\eta)},$$

which, however, cannot be satisfied for any wavelength.

[0029] Accordingly, targets **111**, **112** with periodic structures in the X and Y directions, respectively, may be measured with orthogonal polarizations **121**, **122**, respectively of illumination radiation **120**, as indicated schematically in **Figure 2A**. Measurements may be carried out using two independent channels corresponding to orthogonal polarizations (the corresponding illumination spots are shown schematically by circles **121**, **122**).

[0030] In certain embodiments, targets **100** may be configured, e.g., with respect to the spatial arrangement of cells **101**, **102**, **111**, **112**, to have groups of cells, denoted e.g., by **90A**, **110A**, **110B**, which correspond to the spatial arrangement of cells **91**, **92** in prior art targets **90**. In such configurations, group (target part) **90A** may correspond in its spatial organization to prior art targets **90**, as may groups (target parts) **110A**, **110B**. Moreover, in certain embodiments, such target configurations may be configured to allow and to be measured utilizing simultaneous measurement of two cells using two illumination spots **120** with corresponding polarizations, for example, measuring additional single grating X cell with Y polarization (e.g., cell **111A** with illumination spot **122**) and grating on grating Y cell with X polarization (e.g., cell **102** with illumination spot **121**). In certain embodiments, targets **100** may be configured to have recurring groups (target parts) **110A**, **110B**, having similar spatial arrangement of cells **111**, **102** and **101**, **112**, respectively, so that analogous target parts **110A**, **110B** may be measured sequentially by shifting the illumination field from one to the other (illustrated schematically by an arrow denoted illumination shift **123**) – so that the resulting 8-cell target **100** (including additional cells **111**, **112**) can be measured (using two illumination spots **121**, **122**) during the same time as prior art target **90** is measured using one measurement spot. simplifying the measurement procedures and minimizing the operational changes with respect to measuring prior art targets **90**.

[0031] To summarize, in certain embodiments, SCOL target **100** may comprise, along at least one measurement direction, two cells **101** (and/or **102**) having periodic structures **86A**, **86B** and **87A**, **87B** with a specified coarse pitch at least at two wafer layers **81**, **82**, respectively. Cells **101** (and/or **102**) may have opposite offsets $\pm f_0$ of top periodic structure(s) **86A**, **86B** with respect to bottom periodic structure(s) **87A**, **87B** in the respective layers (as illustrated schematically e.g., in **Figure 1**), and two cells **111** (and/or **112**) having, each, periodic structure(s) **116B**, **117A** with the specified coarse pitch at a different one of the two layers **81**, **82** and sub-resolved periodic structure(s) **116A**, **117B** at the other one of the two layers, **82**, **81**, respectively (as illustrated schematically e.g., in **Figure 2B**). Four cells **101**, **111** (and/or **102**, **112**) may be designed along each of two, X and Y, measurement directions, duplicating the scheme described above to both directions X (with four cells **101**, **111**) and Y (with four cells **102**, **112**), as illustrated schematically, e.g., in **Figure 2A**. In certain embodiments, eight cells (two in each of cells **101**, **102**, **111**, **112**) may be arranged in two groups **110A**, **110B** of four cells each – two X direction cells and two Y direction cells (e.g., **111**, **102** in one group, **101**, **112** in another group, respectively – see **Figure 2A**) - having a same spatial arrangement with respect to the measurement directions. Target design files **99** of any of disclosed targets **100** are likewise part of the present disclosure.

[0032] Advantageously, addition of cells **111**, **112** with sub-resolved periodic structures allows to compensate for the inaccuracies due to grating asymmetries and improves the accuracy with respect to standard DBO techniques. The use of sub-resolved structures **116A**, **117B** instead of gratings **86A**, **87B** in the two additional cells makes sure that the film stack properties are unmodified leading to a better cancellation of the terms that deviate from the ideal signal and hence leading to better overlay accuracy.

[0033] **Figure 3** is a high-level schematic illustration of metrology targets **100**, according to some embodiments of the invention. Targets **100** comprise at least two layers **81**, **82**, each with periodic structures along alternating measurement directions X, Y – periodic structures **131A**, **132A** along measurement directions X, Y, respectively in layer **81** and periodic structures **131B**, **132B** along measurement directions X, Y, respectively in layer

82 – with each periodic structure segmented at an unresolved pitch (e.g., pitch below 300nm, 200nm or below 100nm - as non-limiting example for typical device pitches) and with the periodic structures alternating at a coarse pitch (e.g., between 600 -1000 nm). The coarse pitch is configured to be well resolved by the metrology tool, while the sub-resolved segmentation pitch is uniform through target **100** (in both directions X and Y) and is below the resolution threshold of the metrology tool.

[0034] Targets **100** may be designed to provide the same amplitudes of the first diffraction orders, while providing the phases of the first diffraction orders at a half pitch shift **124** of π between illumination radiation at two orthogonal polarization directions **121**, **122** (shift **124** by pitch/2 is equivalent to a phase shift of π). Accordingly, the change of polarization changes the sign of the term $2\rho\rho'\sin\left(\frac{2\pi\Delta}{P}\right)$ in **Equation 3** (copied below for convenience) for the differential signal *D(x, y)* (with respect to the first and second terms $\rho\delta\rho + \rho'\delta\rho'$of **Equation 3**), whereas the scattering on target asymmetries is only slightly dependent on the changes of polarization (since the most asymmetry is formed not within the segmented parts of target **100** because the sub-resolved segmentation can be designed with minimal design rule pitch and the asymmetric disturbance is an incompact object characterized by a large coarse pitch).

$$D(x,y)=4|E_0|^2\,[\,\rho\delta\rho+\rho'\delta\rho'-2\rho\rho'\sin(\frac{2\pi\Delta}{P})] \qquad \textbf{Equation 3}$$

[0035] Consequentially, targets **100** designed (in both layers **81**, **82**) according to the principles illustrated in **Figure 3** and measured accordingly, to yield half the sum of the overlay values calculated for the two orthogonal polarizations is free of target asymmetry effects.

[0036] To summarize, in certain embodiments, SCOL target **100** may comprise at least at two wafer layers **81**, **82**, periodic structures **131A**, **131B**, **132A**, **132B** having a sub-resolved pitch, which alternate in a corresponding measurement direction to yield a coarse pitch, as illustrated schematically in **Figure 3**. Target design files **99** of any of disclosed targets **100** are likewise part of the present disclosure.

[0037] Advantageously, targets **100** may be configured and measured to eliminate target asymmetry effects, and embodiments of targets **100** which are designed according to the principles illustrated in **Figure 3** require smaller target areas than targets **100** designed according to the principles illustrated in **Figure 2A**.

[0038] **Figure 4** is a high-level schematic illustration of a metrology measurement setting, according to some embodiments of the invention. A metrology tool **70** typically has an illumination arm **120A** delivering illumination radiation **120** onto metrology target **100** (which is produced using target design file(s) **99**) and a measurement arm **125** measuring the resulting signal, in case of SCOL targets **100** – the diffractions orders (typically orders 0, -1 and +1, in the pupil plane) of the radiation scattered off target **100**. A metrology module **140** receives the measured signals and processes them to derive metrology metric(s) such as the overlay between target layers **81**, **82**, as disclosed herein.

[0039] **Figure 5** is a high-level flowchart illustrating a method **200**, according to some embodiments of the invention. The method stages may be carried out with respect to targets **100** described above, which may optionally be configured to allow implementation of method **200**. Method **200** may be at least partially implemented, in its designing and/or measuring aspects, by at least one computer processor, e.g., in metrology module **140**. 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**. Certain embodiments comprise target design files of respective targets designed by embodiments of method **200** and/or measurement results of method **200**. Method **200** may comprise the following stages, irrespective of their order.

[0040] Method **100** may comprise cancelling grating asymmetry effects by target design and measurement configuration (stage **205**), as disclosed herein.

[0041] In certain embodiments, method **200** may comprise adding, to a SCOL target design, cells with periodic structures at one layer and sub-resolved features in other layer(s) (stage **210**), as illustrated schematically in **Figure 2A**. In certain embodiments, method **200** may comprise adding, to a SCOL target comprising, along at least one measurement direction, two cells having periodic structures with a specified coarse pitch at least at two wafer layers, wherein the two cells have opposite offsets of a top periodic structure with respect to a bottom periodic structure in the respective layers - two cells having, each, a periodic structure with the specified coarse pitch at a different one of the two layers and a sub-resolved periodic structure the other one of the two layers. The SCOL target may have the two cells along each of two, X and Y, measurement directions, and adding **210** may be carried out accordingly for the cells of each of the measurement directions.

[0042] In certain embodiments, method **200** may comprise grouping target cells to have similar spatial relations and measuring the groups by shifting the illumination spot (stage **220**), as illustrated schematically in **Figure 2A**. In certain embodiments, method **200** may comprise arranging the eight cells in two groups of four cells each – two X direction cells and two Y direction cells, the groups having a same spatial arrangement with respect to the measurement directions.

[0043] Method **200** may further comprise measuring the augmented SCOL targets (e.g., the SCOL targets with added cells as disclosed above) and/or cells thereof in different directions with orthogonal illumination polarization (stage **250**), e.g., measuring the cells along the two, X and Y, measurement directions with orthogonally polarized illumination radiation **120**. The measuring may be carried out simultaneously for pairs of periodic structures with pairs of orthogonally polarized illumination spots.

[0044] The coarse pitches may be at least 500nm or 600nm and the sub-resolved periodic structure may have sub-resolved pitches smaller than 300nm, 200nm or smaller than 100nm.

[0045] In certain embodiments, method **200** may comprise configuring targets to have periodic structures in measurement directions which alternate at half the coarse pitch (stage **240**) and measuring the augmented targets in different directions with orthogonal illumination polarization (stage **250**). For example, method **200** may comprise measuring, with orthogonally polarized illumination radiation along two measurement directions, a target comprising, at least at two wafer layers, periodic structures having a sub-resolved pitch which alternate in the corresponding measurement direction to yield a coarse pitch. The measuring may be carried out simultaneously for pairs of periodic structures with pairs of orthogonally polarized illumination spots.

[0046] 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.

[0047] 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.

[0048] 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.

[0049] 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.

[0050] 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.

[0051] 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 SCOL (scatterometry overlay) target comprising, along at least one measurement direction:

   two cells having periodic structures with a specified coarse pitch at least at two wafer layers, wherein the two cells have opposite offsets of a top periodic structure with respect to a bottom periodic structure in the respective layers, and

   two cells having, each, a periodic structure with the specified coarse pitch at a different one of the two layers and a sub-resolved periodic structure at the other one of the two layers.
2. The SCOL target of claim 1, having the four cells along each of two, X and Y, measurement directions.
3. The SCOL target of claim 2, wherein the eight cells are arranged in two groups of four cells each – two X direction cells and two Y direction cells – having a same spatial arrangement with respect to the measurement directions.
4. The SCOL target of any one of claims 1-3, wherein the specified coarse pitch is at least 500nm and the sub-resolved periodic structure has a sub-resolved pitch smaller than 300nm.
5. The SCOL target of claim 4, wherein the sub-resolved pitch is smaller than 100nm.
6. A target design file of targets designed according to any one of claims 1-5.
7. A SCOL target comprising, at least at two wafer layers, periodic structures having a sub-resolved pitch, which alternate in a corresponding measurement direction to yield a coarse pitch.
8. The SCOL target of claim 7, wherein the coarse pitch is at least 600nm and the sub-resolved pitch is smaller than 200nm.
9. The SCOL target of claim 8, wherein the sub-resolved pitch is smaller than 100nm.
10. A target design file of targets designed according to any one of claims 7-9.
11. A method comprising adding, to a SCOL target comprising, along at least one measurement direction, two cells having periodic structures with a specified coarse pitch at least at two wafer layers, wherein the two cells have opposite offsets of a top periodic structure with respect to a bottom periodic structure in the respective layers -

two cells having, each, a periodic structure with the specified coarse pitch at a different one of the two layers and a sub-resolved periodic structure the other one of the two layers.

12. The method of claim 11, wherein the SCOL target has the two cells along each of two, X and Y, measurement directions, and the adding is carried out accordingly.
13. The method of claim 12, further comprising arranging the eight cells in two groups of four cells each – two X direction cells and two Y direction cells, the groups having a same spatial arrangement with respect to the measurement directions.
14. The method of claim 12 or 13, further comprising measuring the cells along the two measurement directions with orthogonally polarized illumination radiation.
15. The method of claim 14, wherein the measuring is carried out simultaneously for pairs of cells with pairs of orthogonally polarized illumination spots.
16. The method of any one of claims 11-15, wherein the specified coarse pitch is at least 500nm and the sub-resolved periodic structure has a sub-resolved pitch smaller than 300nm.
17. The method of claim 16, wherein the sub-resolved pitch is smaller than 100nm.
18. A method comprising measuring, with orthogonally polarized illumination radiation along two measurement directions, a target comprising, at least at two wafer layers, periodic structures having a sub-resolved pitch which alternate in the corresponding measurement direction to yield a coarse pitch.
19. The method of claim 18, wherein the measuring is carried out simultaneously for pairs of periodic structures with pairs of orthogonally polarized illumination spots.
20. The method of claim 18 or 19, wherein the coarse pitch is at least 600nm and the sub-resolved pitch is smaller than 200nm.
21. The method of claim 20, wherein the sub-resolved pitch is smaller than 100nm.

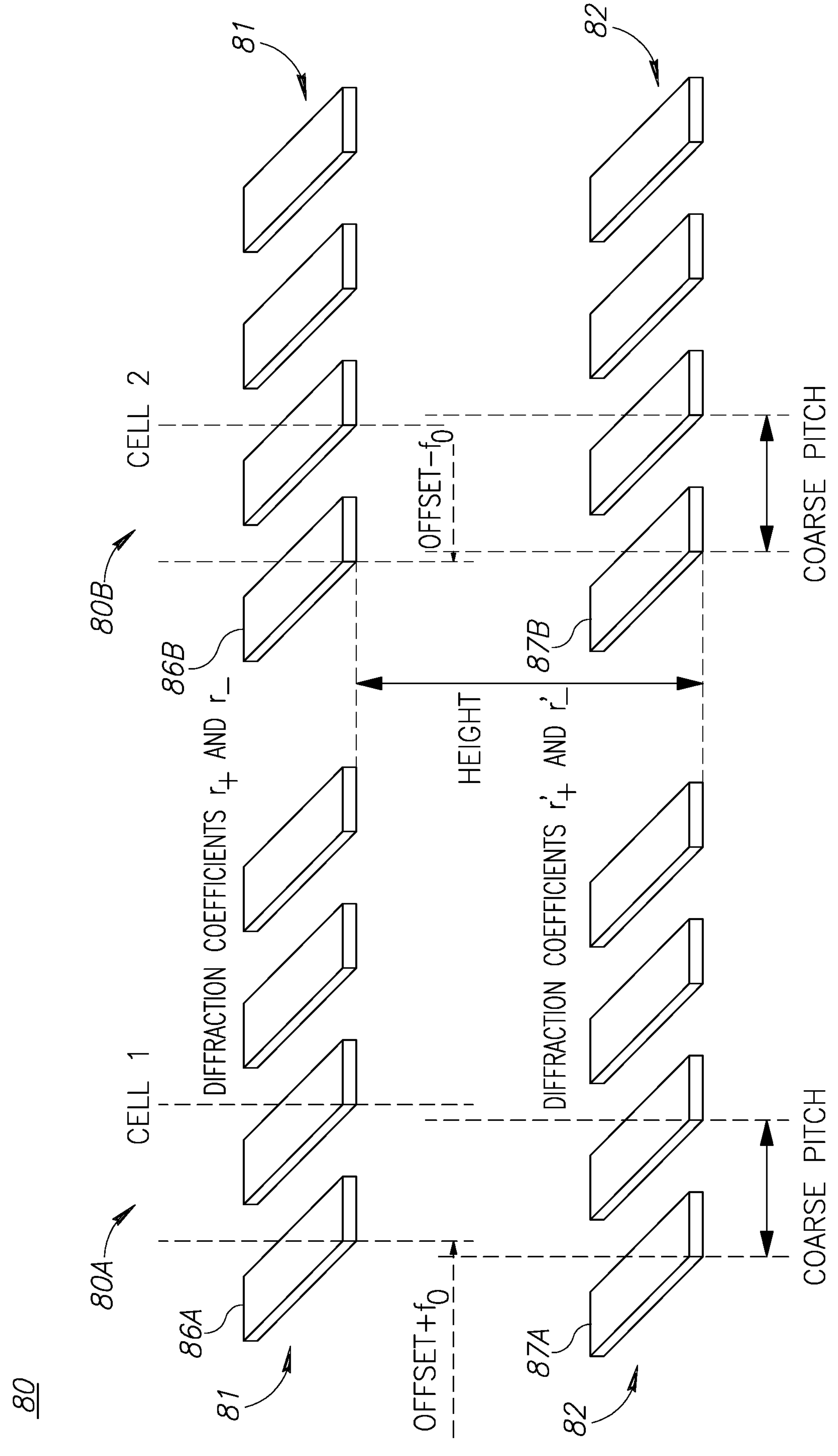
80
80A
80B
81
81
82
82
86A
86B
87A
87B
CELL 1
CELL 2
OFFSET+f_0
OFFSET−f_0
DIFFRACTION COEFFICIENTS r_+ AND r_-
HEIGHT
DIFFRACTION COEFFICIENTS r'_+ AND r'_-
COARSE PITCH
COARSE PITCH

Figure 1

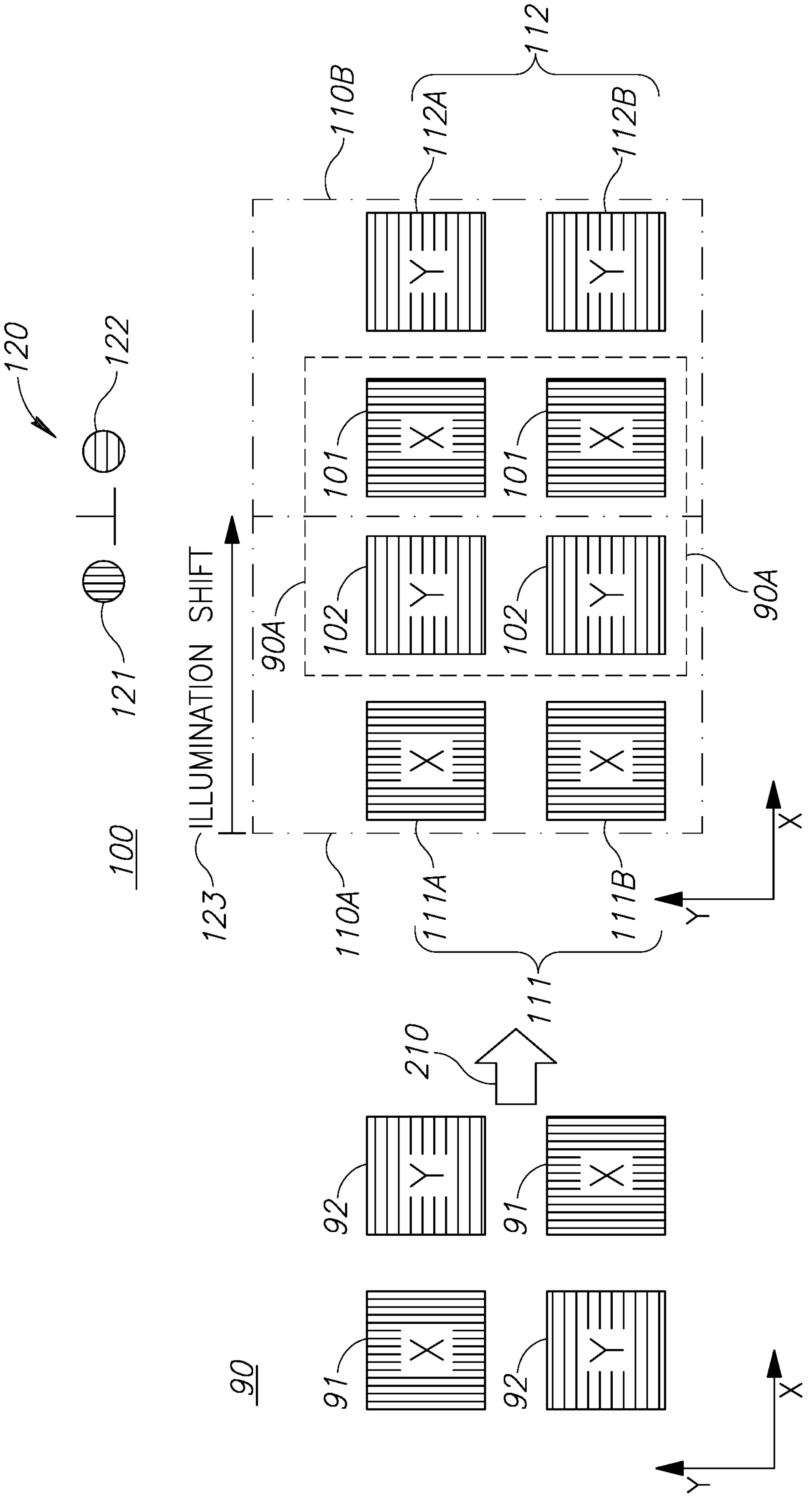
100
90
91
92
X
Y
210
111
111A
111B
110A
123
ILLUMINATION SHIFT
121
122
120
90A
102
101
110B
112
112A
112B

Figure 2A

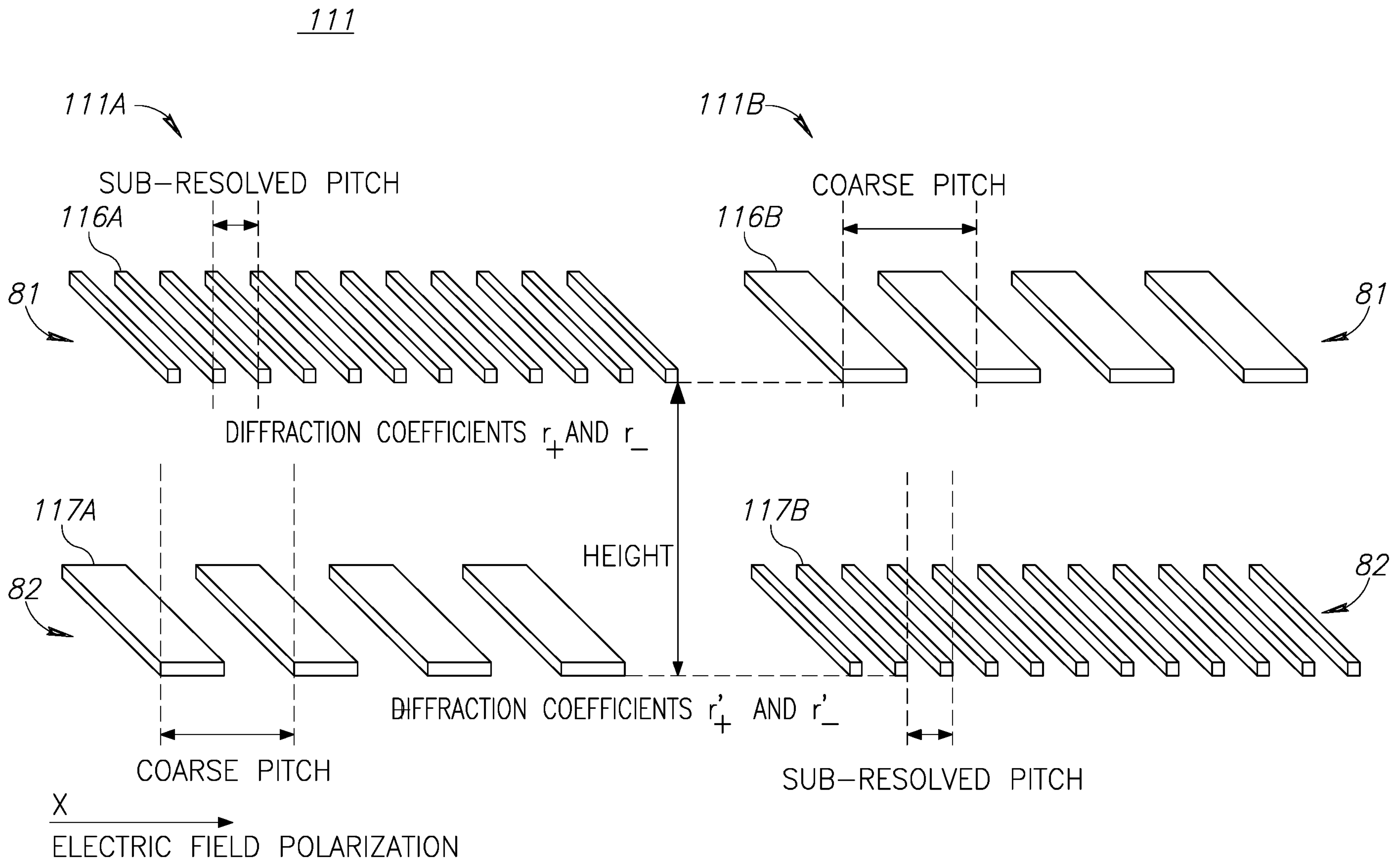
111
111A
111B
SUB-RESOLVED PITCH
COARSE PITCH
116A
116B
81
81
DIFFRACTION COEFFICIENTS r_+ AND r_-
117A
117B
HEIGHT
82
82
DIFFRACTION COEFFICIENTS r'_+ AND r'_-
COARSE PITCH
SUB-RESOLVED PITCH
X
ELECTRIC FIELD POLARIZATION

Figure 2B

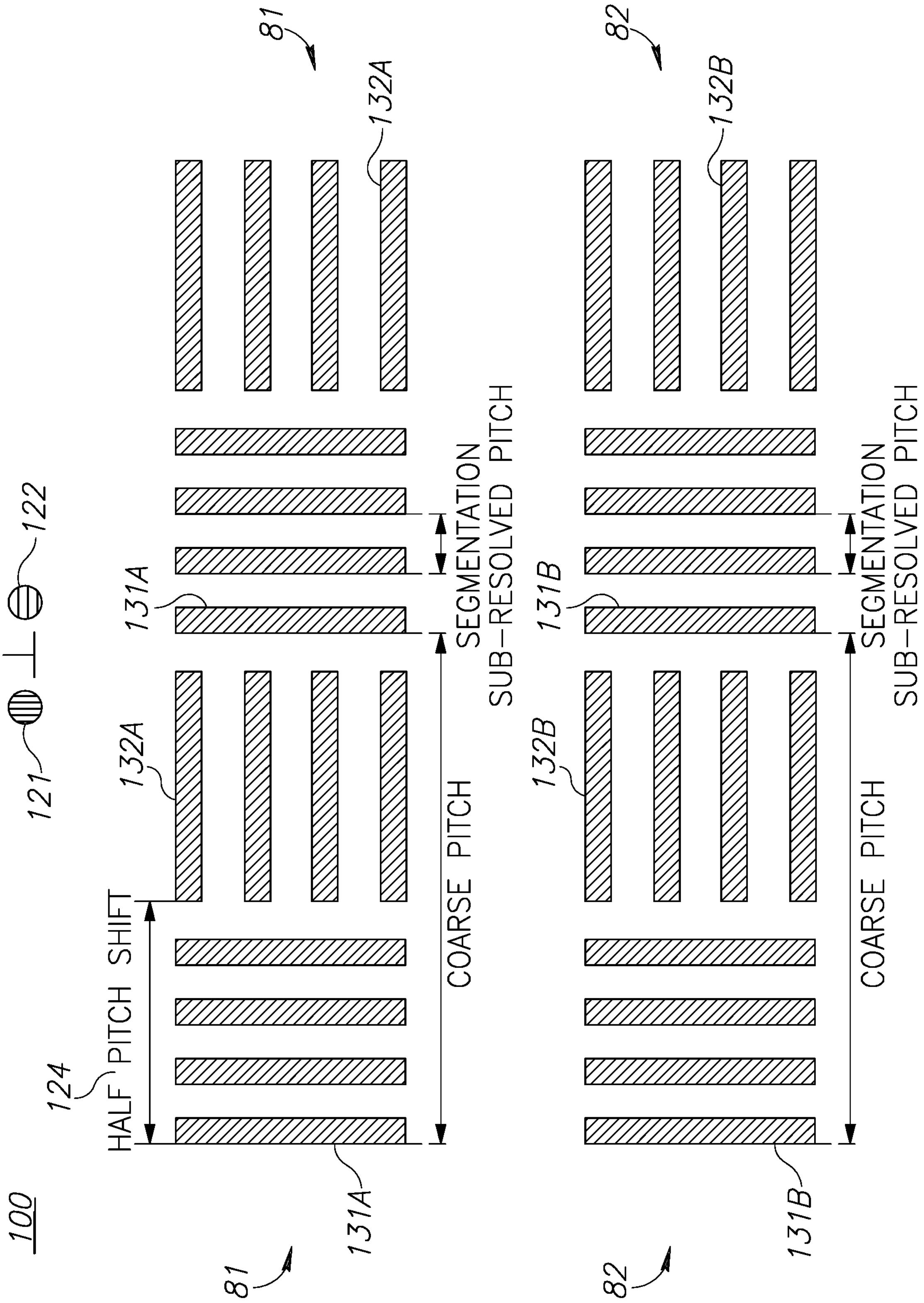
100
120
121
122
124
HALF PITCH SHIFT
81
81
82
82
131A
131A
132A
132A
131B
131B
132B
132B
SEGMENTATION
SUB-RESOLVED PITCH
SEGMENTATION
SUB-RESOLVED PITCH
COARSE PITCH
COARSE PITCH

Figure 3

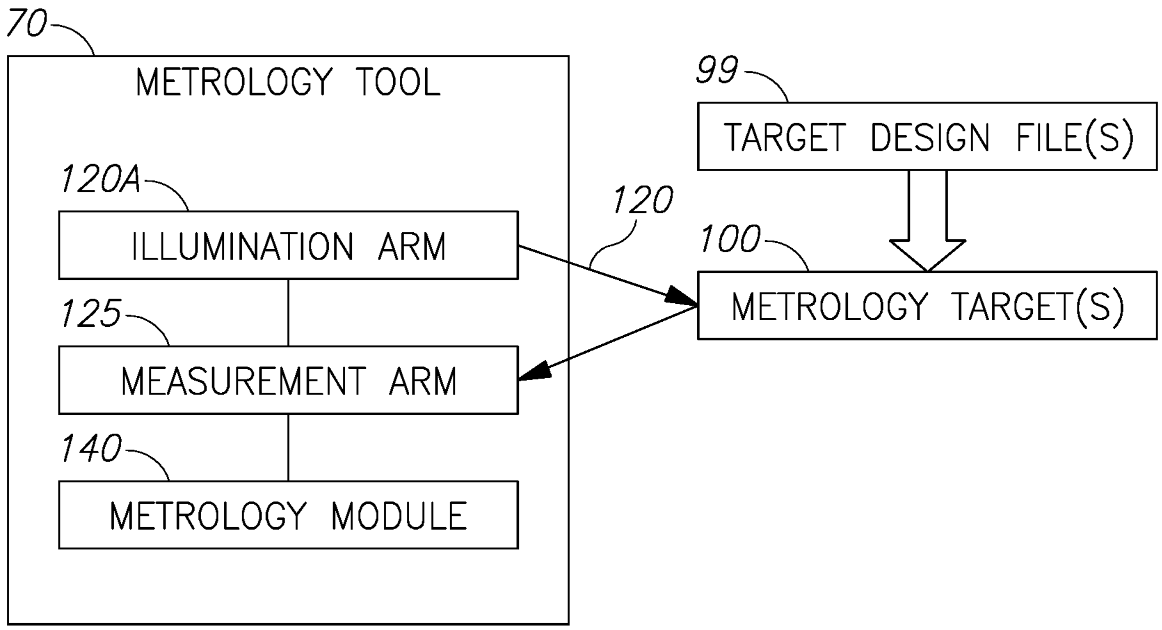
70
METROLOGY TOOL
120A
ILLUMINATION ARM
125
MEASUREMENT ARM
140
METROLOGY MODULE
120
99
TARGET DESIGN FILE(S)
100
METROLOGY TARGET(S)

Figure 4

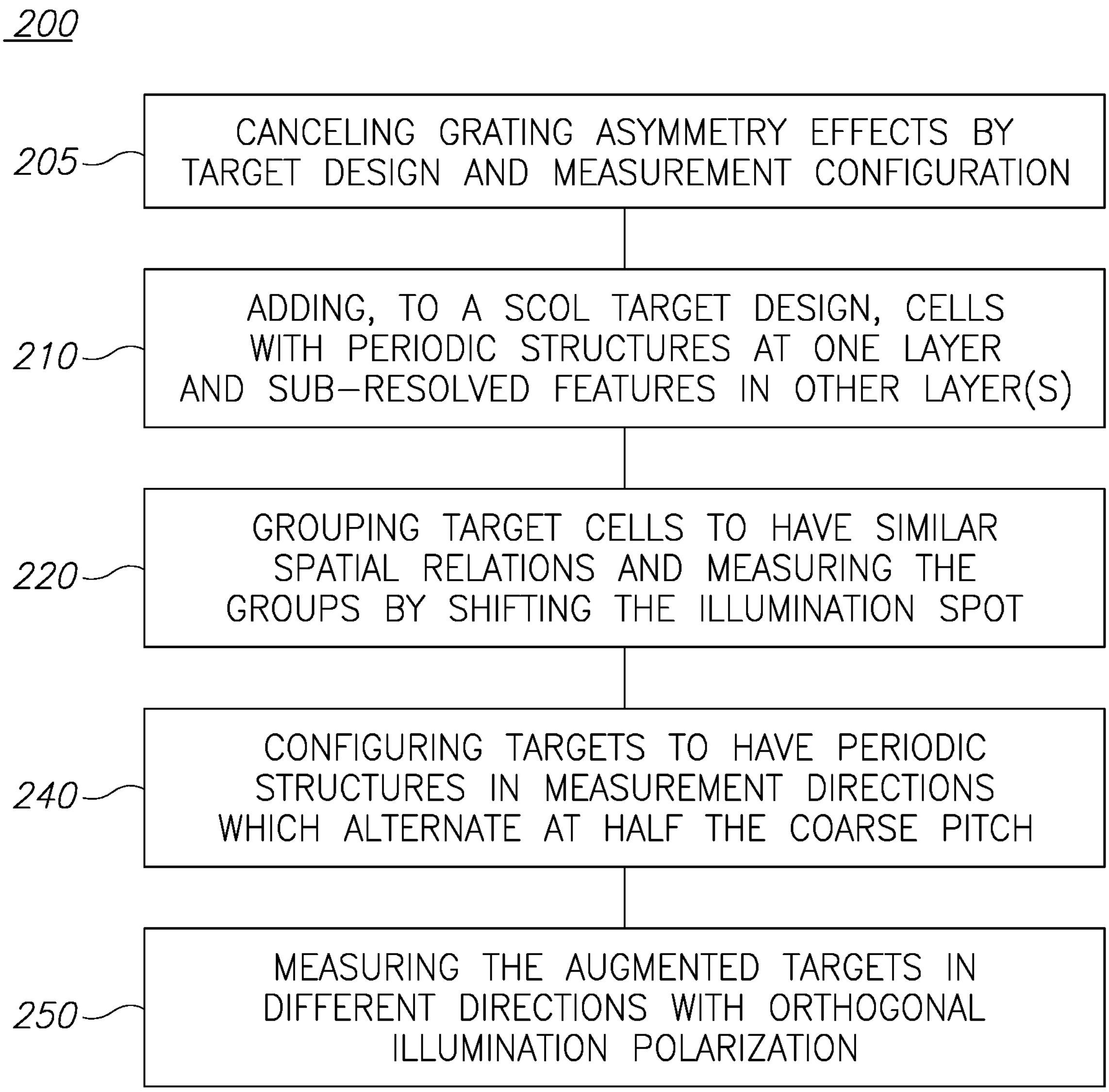
200
205
CANCELING GRATING ASYMMETRY EFFECTS BY TARGET DESIGN AND MEASUREMENT CONFIGURATION
210
ADDING, TO A SCOL TARGET DESIGN, CELLS WITH PERIODIC STRUCTURES AT ONE LAYER AND SUB-RESOLVED FEATURES IN OTHER LAYER(S)
220
GROUPING TARGET CELLS TO HAVE SIMILAR SPATIAL RELATIONS AND MEASURING THE GROUPS BY SHIFTING THE ILLUMINATION SPOT
240
CONFIGURING TARGETS TO HAVE PERIODIC STRUCTURES IN MEASUREMENT DIRECTIONS WHICH ALTERNATE AT HALF THE COARSE PITCH
250
MEASURING THE AUGMENTED TARGETS IN DIFFERENT DIRECTIONS WITH ORTHOGONAL ILLUMINATION POLARIZATION

Figure 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/066853

A. CLASSIFICATION OF SUBJECT MATTER

G03F 7/20(2006.01)i, H01L 21/66(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G03F 7/20; G01B 11/24; H01L 23/544; G01B 11/14; G01N 21/88; G01B 11/00; G01B 11/27; G01N 21/65; H01L 21/66

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: SCOL, scatterometry overlay, target, layer, cell, periodic, offset, coarse pitch, sub-resolved pitch

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2007-0229829 A1 (KANDEL, D. et al.) 04 October 2007 See paragraphs [0036]-[0039], [0080], [0098], [0101]; claims 1, 2, 8, 31, 34; and figures 2(a)-2(h).	1-5,7-15,18-21
Y	US 2013-0342831 A1 (KLA-TENCOR CORPORATION) 26 December 2013 See paragraphs [0031], [0046], [0075]; claim 1; and figures 1-5.	1-5,7-15,18-21
A	WO 2016-187468 A1 (KLA-TENCOR CORPORATION) 24 November 2016 See paragraph [0096]; claims 23, 24; and figure 9.	1-5,7-15,18-21
A	US 2015-0233705 A1 (KLA-TENCOR CORPORATION) 20 August 2015 See paragraph [0025]; claims 1, 8; and figure 1.	1-5,7-15,18-21
A	US 2015-0204664 A1 (KLA-TENCOR CORPORATION) 23 July 2015 See claim 14.	1-5,7-15,18-21

☐ 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
"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 17 April 2018 (17.04.2018)	Date of mailing of the international search report **17 April 2018 (17.04.2018)**
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 Facsimile No. +82-42-481-8578	Authorized officer LEE, Myung Jin Telephone No. +82-42-481-8474

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.: 17
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:
Claim 17 is unclear since it is referring to the multiple dependent claims which do not comply with PCT Rule 6.4(a).

3. ☒ Claims Nos.: 6,16
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/US2017/066853

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		TW 201712435 A	01/04/2017
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US 2015-0233705 A1	20/08/2015	TW 201432830 A	16/08/2014
		TW I598972 B	11/09/2017
		US 9869543 B2	16/01/2018
		WO 2014-074873 A1	15/05/2014
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		US 2016-0216197 A1	28/07/2016
		US 9581430 B2	28/02/2017
		US 9739702 B2	22/08/2017
		WO 2014-062972 A1	24/04/2014