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

(72) Inventors: **LEVINSKI, Vladimir**; Hermon 9, 23100 Migdal Ha'Emek (IL). **MANASSEN, Amnon**; 10 Golda Meir, 34892 Haifa (IL). **AMIR, Eran**; Geva 3/6 Pardes Hanna-Karkur, 37061 Haifa (IL). **AMIR, Nuriel**; 34 Yarden St., 2068101 St. Yokne'am (IL). **YERUSHALMI, Liran**; 43 Inbar, 30900 Zicron Yaacob (IL). **SHAKED, Amit**; 36th Habanim Road Pardes-Hanna, 3707387 Karkur (IL).

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

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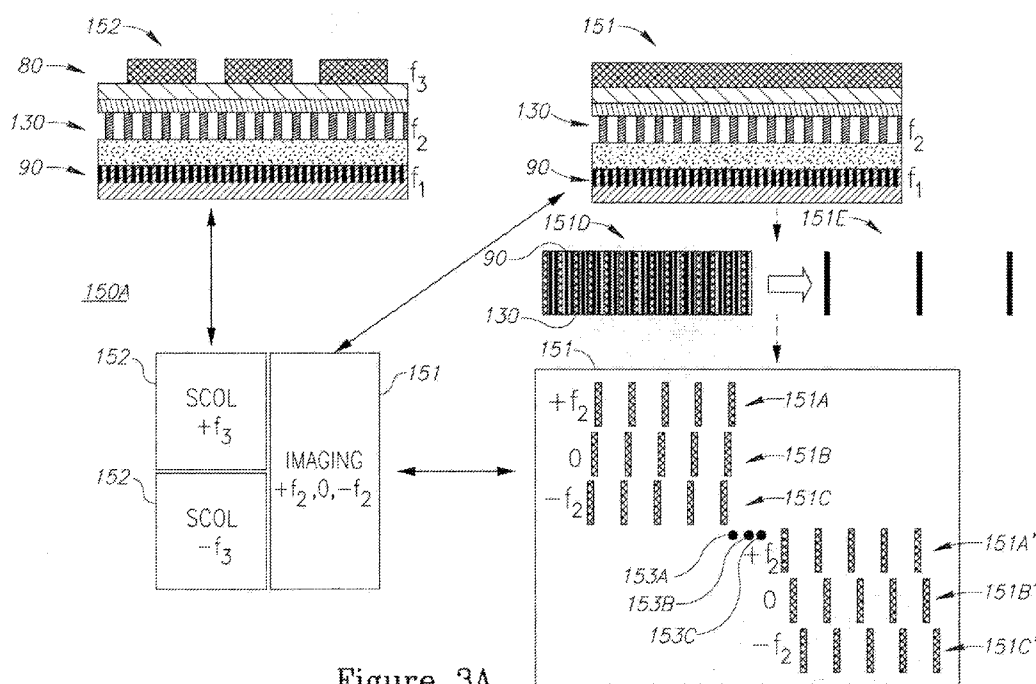


Figure 3A

(57) Abstract: Metrology targets, production processes and optical systems are provided, which enable metrology of device-like targets. Supplementary structure(s) may be introduced in the target to interact optically with the bottom layer and/or with the top layer of the target and target cells configurations enable deriving measurements of device-characteristic features. For example, supplementary structure(s) may be designed to yield Moiré patterns with one or both layers, and metrology parameters may be derived from these patterns. Device production processes were adapted to enable production of corresponding targets, which may be measured by standard or by provided modified optical systems, configured to enable phase measurements of the Moiré patterns.



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DEVICE-LIKE METROLOGY TARGETS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 62/442226 filed on January 4, 2017, and of U.S. Provisional Patent Application No. 62/462877 filed on February 23, 2017, which are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

1. TECHNICAL FIELD

[0002] The present invention relates to the field of metrology, and more particularly, to design, production and measurement of device-like metrology targets.

2. DISCUSSION OF RELATED ART

[0003] As device production processes advance, metrology copes with smaller device details which limit significantly the available overlay budget. Hence new types of targets are required to enable reliable and accurate metrology measurements of small device details.

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 limit the scope of the invention, but merely serves as an introduction to the following description.

[0005] One aspect of the present invention provides a metrology target comprising, between a bottom layer and a top layer each having a corresponding periodic structure, at least one supplementary structure configured to interact optically with at least one of the bottom periodic structure and the top periodic structures.

[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] **Figures 1A-1D** are high level schematic cross section illustrations of multi-layered target structures, according to some embodiments of the invention.

[0010] **Figures 2A and 2B** are high level schematic illustrations of targets that generate Moiré patterns, according to some embodiments of the invention.

[0011] **Figures 3A-3H** are high level schematic illustrations of target structures and configurations, according to some embodiments of the invention.

[0012] **Figures 4A-4D** are high level schematic illustrations of production procedures, according to some embodiments of the invention.

[0013] **Figures 5A-5D** are high level schematic illustrations of optical systems which may be used to measure the targets, according to some embodiments of the invention.

[0014] **Figure 6** is a high level schematic flowchart of a method, according to some embodiments of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0015] Prior to the detailed description being set forth, it may be helpful to set forth definitions of certain terms that will be used hereinafter.

[0016] The term “layer” as used in this application refers to any target layer produced in the photolithography process such as a polysilicon layer, a contact layer, a resist etc. The term “structure” as used in this application refers to any kind of designed or produced structure in at least one layer of a metrology target. The term “periodic structure” as used in this application refers to any kind of

designed or produced structure in at least one layer which exhibits some periodicity. The periodicity is characterized by its pitch, namely its spatial frequency. Elements of the periodic structure may be segmented, i.e., comprise segments that reduce the size of the minimal target feature. An example for a typical periodic structure is a grating. It is noted that periodic structures may represent device elements, or may be device elements.

[0017] The term “metrology target” as used in this application refers to a structure that is used to derive measurements that are indicative of production parameters such as overlay between layers, structure dimensions and any other accuracy merits. Metrology targets may be dedicated structures which are produced for conducting metrology measurements thereupon, or may at least in part comprise actual device elements, that are used to derive measurements at certain production steps. The terms “bottom layer”, “previous layer”, “top layer and “current layer” as used in this application refer to a layer (bottom, or previous) in the metrology target which is deeper and earlier produced than another layer (top, or current) in the target structure. The term “supplementary structure” as used in this application refers to any structure which is added to a design of a metrology target. Supplementary structure may be or comprise periodic structures but are not necessarily periodic, and may be designed and produced in any target layer, including the top and bottom layers and above or below these, respectively. The term “intermediate layer” as used in this application refers to a structure produced in lithography step at a layer that is different from the bottom or top layers. The intermediate layer is illustrated in the following to be between the bottom and top layers. While the illustrations depict supplementary structures as for the sake of simplicity, it is emphasized that the supplementary structure(s) may be not intermediate and/or not periodic, as explained below. In certain embodiments, the supplementary structure(s) may be at the same layer as the previous or current layers. It is noted that same numerals are used to denote a layer and a respective structure in the layer, in order to simplify the explanations.

[0018] With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments 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.

[0019] 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 or of being practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

[0020] Metrology targets, production processes and optical systems are provided, which enable metrology of device-like targets. Supplementary structure(s) may be introduced in the target to interact optically with the bottom layer and/or with the top layer of the target and target cells configurations enable deriving measurements of device-characteristic features. For example, supplementary structure(s) may be designed to yield Moiré patterns with one or both layers, and metrology parameters may be derived from these patterns. Device production processes were adapted to enable production of corresponding targets, which may be measured by standard or by provided modified optical systems, configured to enable phase measurements of the Moiré patterns.

[0021] While it was suggested in the past to create Moiré patterns using the top and the bottom gratings of overlay targets, the signal of prior art structures was often insufficient for optical far-field measurements since the evanescent modes of each grating in this approach decay exponentially and result in weak signals at

most due to the large optical path between the gratings (in the order of hundreds of nm or more).

[0022] Advantageously, the metrology targets enable overlay (OVL) and/or critical dimension (CD) measurement of device patterns, as well as sensitive pitch walk measurements, using intermediate lithography step(s) that are part of the process flow. The targets utilize the strong near field interaction between the previous layer and intermediate layer to yield detectable signals, and enable the previous layer pattern to be much smaller than typical optical resolution limit. These targets thus improve the correlation to the device and the process compatibility.

[0023] Figures 1A-1D are high level schematic cross section illustrations of multi-layered target structures **150**, according to some embodiments of the invention. Targets **150** may comprise a bottom layer having a bottom periodic structure **90**, a top layer having a top periodic structure **80** and supplementary structures **110**, **130** configured to interact optically with at least one of bottom periodic structure **90** and top periodic structure **80**. Any number and types of layers **93** may be included in targets **150**. Supplementary structures **110**, **130** may be periodic, comprise periodic elements and/or be non-periodic.

[0024] Supplementary structure(s) **110**, **130** may be designed to improve the process robustness of the targets (CMP – chemical mechanical planarization). For example, structure(s) **110** and/or **130** may be segmented orthogonally to structures **80**, **90** to minimize their effect on the metrology measurements. In certain embodiments, structure(s) **110** and/or **130** may be designed to improve metrology measurements by any of: (i) maximizing signal transmission from bottom layer **90**, (ii) preventing signal transmission from below layer **110**, (iii) optimizing the bottom and top layers interference signal in SCOL targets, (iv) interacting optically with any or both periodic structures **90**, **80**, e.g., by generating Moiré pattern(s) therewith, and specifically enabling metrology measurement of small scale details like device elements, at least in bottom layer **90**, (v) interacting optically with any or both periodic structures **90**, **80** to yield Moiré pattern(s) in two directions, enabling simultaneous measurements of

overlay and CD (critical dimension), and (vi) functioning as an apodizer to reduce finite target size effects. Some of these possibilities are exemplified in more details below.

[0025] Figure 1A for example, illustrates the supplementary structure as intermediate layer **110** designed as a blocking layer or barrier layer that removes disturbances from lower layers **93** (and specifically **90**) to metrology measurements of target elements above barrier layer **110**. Barrier layer **110** may enable re-using a given area for multiple measurements of different layer and different overlays without disturbances from structures which were previously measured.

[0026] Figure 1B, in another example, schematically illustrates supplementary structure **130** which may interact optically with bottom periodic structure **90** and/or with top periodic structure **80**. In the illustrated example, bottom layer has small scale details (e.g., tens of nm), e.g., device or device-like features, while top layer has larger scale details (e.g., hundreds of nm), typical for providing optical metrology measurements. Supplementary structure **130** may be designed at a scale similar to bottom periodic structure **90** and to interact optically therewith. Simulations with various top layer CD and intermediate layer space CD's have shown sensitivity of the overall metrology measurements of targets **150** to structure details of bottom periodic structure **90**, i.e., to details in the scale of several tens of nm. In the simulated example, the pitches of structures **90**, **130** were 80nm and 90nm respectively and the pitch of structure **80** was 720nm.

[0027] Figures 1C and 1D schematically illustrate bottom layer periodic structure **90** comprising multiply patterned elements **109** which are produced in multi-patterning steps (i.e., elements produced by double, quadruple or generally multiple patterning), for example - finFET ("fin" field effect transistor) elements, which may have an even smaller pitch of few tens of nm. **Figure 1C** and **Figure 1D** illustrate examples of multiply patterned elements **109** (as finFETs) produced by quadruple patterning and exhibiting a periodicity in groups of four elements **109**. Using a cut process, fin elements **109** may be remove selectively and periodically, e.g., in **Figure 1C** every fifth fin element is removed (the gap being

marked **109A**) while in **Figure 1D** every fourth fin is removed **109A**. Supplementary structure **130** may be configured to interact optically with bottom multiply patterned (e.g., finFET) periodic structure **90** and enable optical metrology measurements thereof. In certain embodiments, target **150** may comprise four cells, wherein in each of the cells a different element in each repeating group is removed **109A**, to enable measuring the inaccuracy in the production of each aspect of the patterning process separately. Simulations have shown that the resulting measurements are sensitive to the placement error of selected missing elements **109A**, e.g., when respective Moiré patterns are generated by appropriately designed intermediate layer **130**. In the simulated example, the CD of finFET elements **109** was 10nm and their pitch was in the order of 40nm.

[0028] Hence, in certain embodiments, bottom layer **90** of targets **150** may comprise a plurality of periodic multiply patterned elements **109**, produced in multiple patterning steps, with which supplementary structure **130** is configured to interact optically. Elements **109** may comprise recurring sets of corresponding elements **109**, and target **150** may comprise multiple cells, each lacking a different one of the elements (**109A**) in the recurring set. Multiply patterned elements **109** may be FinFET elements.

[0029] **Figures 2A** and **2B** are high level schematic illustrations of targets **150** that generate Moiré patterns, according to some embodiments of the invention. **Figures 2A** and **2B** present schematic cross section illustrations of imaging targets **151** and SCOL targets **152** (e.g., first order SCOL) respectively, as examples for targets **150**. It is explicitly noted, that while in the illustrated examples, supplementary structure **130** are physically between top and bottom periodic structures **80**, **90**, supplementary structures **130** may as well be located below bottom periodic structures **90**, and even may be part of the lowest silicon layer.

[0030] In certain embodiments, bottom and top periodic structures **90**, **80** respectively, have a same pitch (P) and supplementary structure **130** may be a periodic structure having a pitch ($P+\Delta P$) that is different from the same pitch (P)

to an extent that generates a detectable Moiré pattern between periodic structures (90, 130 and 80, 130).

[0031] Corresponding Moiré patterns may be generated using supplementary structure 130 (e.g., having a silicon grating) for measuring overlay between layers 80, 90. Targets 150 may overcome the difficulty that introducing supplementary structure 130 potentially involves new unknown parameter(s) like the overlay between supplementary structure 130 and other layers 93, including periodic structures 80, 90. Thus, while supplementary structure 130 may help in pitch reduction, it may require additional cells and additional measurements to determine its overlay. However, the proposed solution, in which supplementary periodic structure 130 creates Moiré patterns with both bottom and top periodic structures 90, 80 by having pitch $P+\Delta P$ which is slightly different (larger or smaller) from pitches P of bottom and top periodic structures 90, 80.

[0032] In certain embodiments, target 150 may be configured as imaging target 151 having at least a first cell 151A with top and supplementary structures 80, 130 respectively, and a second cell 151B with bottom and supplementary structures 90, 130 respectively. While pitches P and $P+\Delta P$ may be unresolved, Moiré pitch $P(P+\Delta P)/\Delta P$ may well be resolved by metrology tools. Denoting the position of the resist grating (top periodic structure 80) as UG (for “upper grating”); the position of the process layer grating (bottom periodic structure 80) as BG (for “bottom grating”); and the position of supplementary structure 130 (which may be below bottom periodic structure 90) as IG (for “intermediate grating”, in a non-limiting manner) – two overlays may be defined, namely $OVL1=UG-BG$ (which is the value the metrology intends to report) and $OVL2=UG-IG$ (which is a byproduct of the target design). Considering a simplified model with only 0 and ± 1 diffraction orders and normal illumination, noting that the most general case yields similar results, measuring first cell 151A provides a sum of zero and first diffraction orders with the difference of topographic phases between zero and first diffraction orders being denoted as Ψ . First diffraction orders with effective pitch are the result of double scattering on intermediate (supplementary) and resist layers (130, 80 respectively, top layer 80

is also termed resist or coarse pitch layer), i.e., +1 coarse diffraction order = +1 resist diffraction order and – 1 intermediate diffraction order and vice versa, as expressed in **Equation 1**:

$$E \cong e^{ikx \sin(\theta_0)} \left(A_0 e^{i\Psi} + A_1 \cdot e^{i\frac{2\pi}{P}(x-UG) - i\frac{2\pi}{P+\Delta P}(x-IG)} + A_1 \cdot e^{-i\frac{2\pi}{P}(x-UG) + i\frac{2\pi}{P+\Delta P}(x-IG)} \right)$$

$$= e^{ikx \sin(\theta_0)} \left(A_0 e^{i\Psi} + 2A_1 \cos \left[\frac{2\pi\Delta P}{P(P+\Delta P)}x - \frac{2\pi}{P}UG + \frac{2\pi}{P+\Delta P}IG \right] \right)$$

Equation 1

Substituting $IG=UG-OVL2$, the measured signal is a function of $x - UG - OVL2 \frac{P}{\Delta P}$, i.e., may be denoted as $F_1(x - UG - OVL2 \frac{P}{\Delta P})$. For second cell **151B**, similar considerations yield **Equation 2**:

$$E = e^{ikx \sin(\theta_0)} \left(B_0 + B_1 \cdot \cos \left[-\frac{2\pi}{P}BG + \frac{2\pi}{P+\Delta P}IG + 2\pi x \frac{\Delta P}{P(P+\Delta P)} \right] \right) =$$

$$= e^{ikx \sin(\theta_0)} \left(B_0 + B_1 \cdot \cos \left[-\frac{2\pi}{P}UG + \frac{2\pi}{P}OVL1 + \frac{2\pi}{P+\Delta P}IG + 2\pi x \frac{\Delta P}{P(P+\Delta P)} \right] \right)$$

Equation 2

[0033] Substituting $IG=UG-OVL2$ and $BG=UG-OVL1$, the measured signal is a function of $x - UG - OVL2 \frac{P}{\Delta P} + OVL1 (P + \Delta P)/\Delta P$, i.e., may be denoted as $F_2(x - UG - OVL2 \frac{P}{\Delta P} + OVL1 (P + \Delta P)/\Delta P)$. The difference between the two cell measurement functions depends only on $OVL1$ (and not on IG) and therefore overlay may be expressed as $OVL = -\frac{\Delta P}{P+\Delta P} \cdot \text{Distance}$, with Distance being the difference in the OVL as measured using the two cells **151A**, **151B**.

[0034] In certain embodiments, target **150** may be configured as scatterometry overlay (SCOL) target **152** comprising bottom, intermediate and top layers **80**, **130** and **90** respectively, in at least one cell. In this case, the first order signal in the pupil, for example, may be expressed by **Equation 3**:

$$E = e^{ikx \sin(\theta_0)} \left(A_1 \cdot e^{i \frac{2\pi}{P} UG - i \frac{2\pi}{P+\Delta P} IG} + B_1 \cdot e^{i \frac{2\pi}{P} BG - i \frac{2\pi}{P+\Delta P} IG} \right)$$

In this case the measured signal (which is the intensity) doesn't depend on position of intermediate grating **130** at all.

[0035] These derivations provides a large flexibility in positioning supplementary structure(s) **130**, while enabling the use of supplementary structure(s) **130** in bridging small scale device features and the larger scale required for optical metrology measurements.

[0036] **Figures 3A-3H** are high level schematic illustrations of target structures and configurations, according to some embodiments of the invention. **Figures 3A-3H** schematically illustrate targets **150A-H** respectively and include both cross sectional illustrations as well as high level cells organization of targets **150**.

[0037] Certain embodiments comprise metrology targets **150** comprising at least two SCOL cells **152** having opposite designed offsets (+f₃, -f₃) between top periodic structure **80** and bottom periodic structure **90** and at least one imaging cell **151** lacking top periodic structure **80** and having at least three supplementary structure s **130**, two of which having opposite offsets (+f₂, -f₂) and one of which having no offset (0) of supplementary structure **130** with respect to bottom periodic structure **90**.

[0038] Supplementary structure(s) **130** may be configured to yield Moiré patterns **151E** by optical interaction with corresponding bottom periodic structures **90**, which are measured with respect to corresponding top periodic structures **80**. The formation of Moiré patterns **151E** is illustrated schematically in a top view **151D** of structures **90**, **130** and the resulting optical interaction **151E** between them.

[0039] **Figure 3A** schematically exemplifies targets **150A** having SCOL cells **152** with layers **90**, **130**, **80** and imaging cells **151** with layers **90**, **130**, according to some embodiments of the invention. SCOL cells **152** may be measured to find the overlay between top periodic structure **80** (e.g., a resist layer) and the Moiré pattern resulting from the optical interactions of layers **90**, **130**, while imaging

cell(s) **151** may be used to determine the overlay between supplementary structure(s) **130** and bottom periodic structure **90**. Imaging cells **151** are exemplified in a non-limiting manner in an AIM (advanced imaging metrology) design having three pairs of cells: **151A** and **151A'** with offset $+f_2$, having center **153A**; **151B** and **151B'** with offset 0, having center **153B**; and **151C** and **151C'** with offset $-f_2$, having center **153C**. Imaging cells in a perpendicular direction may be added to the design. It is noted that other layers **93** including the top layer may have structure, but such which do not interfere optically with supplementary structures **90**, **130**. The overlay between supplementary structure **130** and periodic structure **90** can be extracted from these three centers (for example, if $153C-153B=153B-153A$ then $OVL=0$).

[0040] In certain embodiments, imaging cell(s) **151** may be measured prior to production of top layer **80**, i.e., prior to production of top periodic structure **80**, e.g., after the etch of supplementary structure **130**, while SCOL cells **152** may be measured after production of top periodic structure **80** for the overlay between structure **80** and Moiré pattern **151C** (which is measured directly using imaging cells **151**).

[0041] Figure 3B schematically exemplifies targets **150B** having imaging cells **151** with layers **90**, **130**, **80**, according to some embodiments of the invention. Certain embodiments comprise metrology targets **150** comprising at least one imaging cell **151** having at least three supplementary structure s **130**, two of which having opposite offsets ($+f_2$, $-f_2$) and one of which having no offset (0) of supplementary structure **130** with respect to bottom periodic structure **90**. For example, imaging cells **151** may be organized as illustrated in Figure 3A.

[0042] It is noted that in certain embodiments, the OVL measurements between **80** and **90** may be replaced by any arrangement which conveys phase information (see e.g., Figures 5A-5D below) such as interfering two diffraction orders (e.g., zeroth and first orders), e.g., by using finite elements along the optical axis such as a specified finite field stop a specified finite cell size etc.

[0043] Figure 3C schematically exemplifies targets **150C** having imaging cells **151A**, **151B** relating to different Moiré patterns, according to some embodiments

of the invention. Each of at least two imaging cells **151** may have at least three supplementary structures **130**, two of which having opposite offsets and one of which having no offset of supplementary structure **130** with respect to bottom periodic structure **90**, wherein in one of imaging cells **151**, supplementary structure **130** may be configured to form a detectable Moiré pattern with bottom periodic structure **90** and in another one of imaging cells **151**, supplementary structure **130** may be configured to form a detectable Moiré pattern with top periodic structure **80**.

[0044] In certain embodiments, supplementary structure **130** can interfere with top periodic structure **80** to form one Moiré pattern (e.g., having pitch P_2) as well as with bottom periodic structure **90** to form another Moiré pattern (e.g., having pitch P_1), as illustrated schematically in **Figure 3C**. Different illumination wavelengths and/or apodizations and/or illumination angles may be selected to determine which of the modes propagates and accordingly which Moiré pitch is measured. Different imaging cells **151A**, **151B** may be designed to enable measurement of different Moiré pitches P_1 , P_2 in different cells **151A**, **151B**, for example by measuring P_1 before production of layer **80** and/or using barrier layer **110** above bottom layer **90** before measuring P_2 . Alternatively or complementarily, the measurement system may be configured to separate pitches P_1 , P_2 at the image plane. Given and unknown overlay, designed offsets between layers **90**, **130**, **80** may be designed to enable at least three measurements, from which the unknown overlay may be extracted.

[0045] **Figures 3D** and **3E** schematically illustrates targets **150D**, **150E** being arrays of imaging cells, according to some embodiments of the invention. In certain embodiments, metrology target **150** may comprise an array of imaging cells, each cell having different combinations of designed offsets $\pm f_2$, $\pm f_3$ between top, intermediate and bottom periodic structures **80**, **130**, **90**. Array **150D** may comprise at least nine cells **152A-J** with all combinations of opposite and zero designed offsets, $\pm f_2$, $\pm f_3$, 0, between the layers. Array **150E** may comprise at least five cells **152A-E**, each cell having no offset or a single one of opposite offsets $\pm f_2$, $\pm f_3$, 0, between bottom periodic structure **90** and one of intermediate

and top periodic structures **130**, **80**, respectively. As before, different illumination wavelengths and/or apodizations and/or illumination angles may be selected to determine which of the modes propagates and accordingly which Moiré pitch is measured.

[0046]Figure 3F schematically exemplifies targets **150F** having SCOL cells **152** and an imaging cell **151** for measuring offsets with respect to finFET elements, according to some embodiments of the invention. Bottom periodic structure **90** may be created using multiple lithography steps (for example: Self-Aligned Quadruple Patterning - SAQP and cut).

[0047]Figure 3G schematically exemplifies targets **150G** having two imaging cells **151A**, **151B**, according to some embodiments of the invention. In certain embodiments, metrology target **150** may comprise at least two imaging cells **151A**, **151B**, each having at least three supplementary structures **130**, two of which having opposite offsets ($\pm f_2$, $\pm f_3$), and one of which having no offset (0) of supplementary structure **130** with respect to bottom periodic structure **90**. In one of imaging cells **151B** the offset ($\pm f_2$) is between supplementary structure **130** and bottom periodic structure **90** and in another one of imaging cells **151A** the offset ($\pm f_3$) is between top periodic structure **80** and bottom periodic structure **90**.

[0048]Figure 3H schematically exemplifies targets **150H** having two pairs of SCOL cells **152A**, **152B**, according to some embodiments of the invention. Metrology target **150** may comprise at least two SCOL (e.g., first order SCOL) cell pairs **152A**, **152B** having opposite designed offsets, one pair **152A** having the designed offsets ($\pm f_3$) between top periodic structure **80** and bottom periodic structure **90**, and another pair **152B** lacking top periodic structure **80** and has the designed offsets ($\pm f_2$) between supplementary structure **130** and bottom periodic structure **90**. In order to measure the latter, a modified optical system may be used, for example, modified optical systems disclosed below, e.g., in **Figures 5A-5D**.

[0049]Figures 4A-4D are high level schematic illustrations of production procedures **160**, according to some embodiments of the invention. Device production procedures **160** (e.g., multiple patterning procedures) may be

configured to enable production of any of targets **150** and in particular of supplementary structure **130**, possibly without adding lithography steps to the device manufacturing process. It is noted that while supplementary structure(s) **130** are illustrated in **Figures 4A-4D** as intermediate layers **130**, supplementary structure(s) **130** may also be produced at the same physical layer as bottom or top layers **90**, **80** (respectively) and/or below bottom layer **90** or above top layer **80**. In certain embodiments, several supplementary structures **130** may be produced. It is further noted that supplementary structures **130** may but must not be periodic.

[0050] **Figure 4A** schematically illustrates the use of selective etch of device pattern followed by deposition in to enable measurements of device edges, according to some embodiments of the invention. The additional deposition is needed in order to enable the measurements by depositing material with different optical properties. Exemplary production procedures **160** comprises the following steps:

[0051] Starting (**160A**) with a pad with a periodic structure **161** (such as a device grating, e.g., finFET elements with minimal pitch), lithography steps (**160B**) may involve placing, exposing and developing resist **163A** with a pitch which is resolved by metrology. Then, etch steps **160C** follow (possibly several process steps) in which resist pattern **163A** is moved to the previous layer pattern, including periodic structure **161**. The last step of etch steps **160C** may be a selective etch which removes only one material from the bottom grating (periodic structure **161**). Then, the etched volumes may be filled with material **164A** which has significantly different optical properties than the etched out material(s) in the bottom layer (**160D**) and the layers above the bottom grating may be removed (**160E**), e.g., employing planarization. Remaining structures **161A**, **161B** may be made of different materials. Following depositions of additional layers, imaging targets may be produced (**160F**) by placing, exposing and developing a resist pattern for the current layer (**80**) on top of a pad next to the pad processed in steps **160A-E**, and/or scatterometry targets may be produced (**160G**) by placing, exposing and developing a resist pattern for the current layer (**80**) on top of the

pad processed in steps **160A-E**. It is noted that production procedures **160** may be modified to yield various patterning options **165A**, **165B**, **165C**, depending on the parameters and directions of original periodic structure **161** and of resist pattern **163A** deposited in step **160B**.

[0052] It is emphasized that production procedures **160** utilize the selective etch and deposition steps which are part of the device lithography process - to create metrology targets, so that the metrology target edges in one direction are defined by the device edges and generally to improve the process compatibility of metrology targets **150**.

[0053] **Figure 4B** schematically illustrates the use of an additional hard mask **163B** in enabling measurements of the overlay between bottom periodic structure **90** representing or actually being the device pattern, and current layer pattern **163B**. The measurement may be incorporated as part of the device production process, e.g., as part of Litho-Etch-Litho-Etch (LELE) production procedure **160** which is identical to the device production flow, according to some embodiments of the invention. Supplementary (intermediate) layer **130** with supplementary structures may be produced above bottom layer **90** and have a pitch which is selected to interact optically with bottom structure **90** and/or top structure **80** (illustrated as mask **163B** in **Figure 4B**).

[0054] **Figure 4C** schematically illustrates creating supplementary structure **130** by production procedures **160**, according to some embodiments of the invention. Following the application of mask **163A** (**160B-C**, comprising depositing the mask and removing material volumes which are not protected thereby, respectively) to produce one type of material in intermediate layer **130** (**160D**), spaces between the elements are filled with a second material **164A** (**160E**) and finally top layer **80** is deposited, possibly after measurements of supplementary structures **130** and bottom layer **90**, as explained above. It is noted that in standard metrology targets there is no pattern in intermediate layer **130** (of second material **164A**).

[0055] **Figure 4D** schematically illustrates creating a single layer, comprising both bottom periodic structure **90** and supplementary structure **130**, and

exhibiting a Moiré pattern upon optical measurement, according to some embodiments of the invention. The single layer may be produced using multiple lithography steps **160A-E**, e.g., lithography and cut step(s) or LELE in production procedures **160**. For example, the process may be designed to yield elements **161A** of bottom periodic structure **90** and filling elements **161B** that define the positions for elements **164A** of supplementary structure **130**. In certain embodiments, the single layer may comprise supplementary structure(s) **130** made of a material **164A** that is different from the material of bottom periodic structure **90**.

[0056] It is noted that even though the illustrations in **Figures 4B** and **4D** may suggest that structure **164A** may violate some design rules (such as minimal tip to tip distance), this issue may be easily resolved by choosing the proper pitches for structure **130** in **Figure 4B** and for structures **130** and **90** in **Figure 4D**.

[0057] Advantageously, production procedures **160** overcomes inaccuracies involved in current metrology targets which have target dimensions different from device dimensions, such as their different response to scanner aberrations and to other variables of the manufacturing process which may affect the overlay, the geometry, LER (line edge roughness) etc.

[0058] **Figures 5A-5D** are high level schematic illustrations of optical systems **170** which may be used to measure targets **150**, according to some embodiments of the invention. Optical systems **170** are designed to derive phase information, e.g., from targets **150**, of Moiré patterns generated by targets **150**, and in certain cases in place of SCOL cells **152**. It is noted that in the far field overlays in Moiré patterns may result in phase differences rather than intensity differences between the 1st and -1st diffraction orders, and hence, phase information may be preferable to direct 1st order SCOL measurements. Illustrated optical systems **170** demonstrate, in a non-limiting manner, implementations for interfering diffraction orders in order to extract phase information they carry.

[0059] Optical systems **170** comprise an illumination source **61**, illumination field stop and lenses **62**, beam splitter **65** through which the illumination is delivered to

objective **66** and onto target **150** on wafer **60**, and then back through optical elements such as lens **68A** to detector **69** such as a CCD (charge-coupled device).

[0060] Figures **5A** and **5B** illustrate the use of apodizer **64** and/or finite field stops **68** configured to diffract the orders so that specified orders, e.g., the zeroth and the first orders (+1 or -1) overlap and provide phase information. Any type of apodizer **64** and field stop **68** may be used, e.g., diffractive or transmissive elements. Field stop **62** may be introduced with corresponding optical elements to modify the length of the collection optical pathway.

[0061] Certain embodiments comprise metrology optical system **170** comprising at least one of apodizer **64** and field stop **68**, configured to interfere the zeroth order reflected diffraction signal with the first order reflected diffraction signal at a pupil plane in which detector **69** is located.

[0062] Figure **5C** illustrates exemplary optical system **170** for interfering +1 diffraction order with -1 diffraction order by reflecting the captured beam using optical element **67D** (e.g., comprising corresponding lenses) and superposing reflected pupil plane image **175B** onto original pupil plane image **175A** using beam splitters **67A**, mirrors **67C** and shutters **67B**.

[0063] Shutters **67B** are used to regulate beam intensities, to correct for beam attenuation during their manipulation (e.g., attenuation of the reflected beam). Specifically, an attenuation factor a can be measured using **Equation 4**, with E_R and E_L denoting the electric field resulting from each of the optical paths and (k_x, k_y) denoting the pupil coordinates:

$$E_R(k_x, k_y) = aE_L(-k_x, -k_y) \quad \text{Equation 4}$$

The signal resulting from the interference of +1 and -1 orders (which have positive and negative k values, respectively), which depends on the overlay, may be expressed as in **Equation 5**:

$$E(k_x, k_y) = E_R(k_x, k_y) + aE_L(-k_x, -k_y) \quad \text{Equation 5}$$

The measured intensity $I(k_x, k_y)$ depends of the overlay, as expressed in **Equation 6**, with P_1 , P_2 denoting the Moiré pitches and ε_1 and ε_2 denoting the lateral position of the first and second gratings:

$$I(k_x, k_y) \approx |E_R|^2 \left[1 + a^2 + 2a \cos \left(4\pi \left(\frac{\varepsilon_1}{P_1} - \frac{\varepsilon_2}{P_2} \right) \right) \right]$$

Equation 6

Equation 6 shows that the measured intensity depends on the OVL (for example, by choosing $\varepsilon_1=0$ and $\text{OVL}=\varepsilon_2$, without loss of generality).

[0064] Certain embodiments comprise metrology optical system **170** comprising an optical assembly (e.g., beam splitters **67A**, shutters **67B**, mirrors **67C** and optical element **67D**) configured to interfere a part of the reflected signal (**175A**) with a mirror image thereof (**175B**) to yield, at a pupil plane in which detector **69** is located, an interference of the +1 first order reflected diffraction signal with the -1 first order reflected diffraction signal. In **Figure 5C** the location of **67C** elements may be modified mechanically to control the optical path. In addition phase modulating element(s) may be added to control the phase of the illumination which is interfered with the signal.

[0065] **Figure 5D** illustrates exemplary optical system **170** for interfering the pupil signal with a uniform field across the pupil to create overlay sensitivity. In the illustrated example, beam splitters **67A**, mirror **67C** and attenuator **67E** are used to introduce some of the illumination as the uniform field and adjust the intensity thereof, to interfere with the collected signal. In certain embodiments, optical systems **170** may interfere the signal with an external uniform beam (for example, by replacing mirror **67C** with an additional illumination source).

[0066] Certain embodiments comprise metrology optical system **170** comprising an optical assembly (e.g., beam splitters **67A**, mirror **67C** and attenuator **67E**) configured to interfere a part of the illuminated radiation with the collected signal to derive phase information of the reflected signal.

[0067] In certain embodiments, optical system **170** may be configured to measure the metrology signal in a field plane, in which the diffraction orders interfere, to derive the overlay from the phase information contained in this interference. In certain embodiments, optical system **170** may be configured to provide ellipsometry measurements that contain the required phase information.

[0068] **Figure 6** is a high level schematic flowchart of a method **200**, according to some embodiments of the invention. Method **200** may be at least partially

implemented by at least one computer processor, e.g., in a metrology module. Certain embodiments comprise computer program products comprising a computer readable storage medium having computer readable program embodied therewith and configured to carry out of the relevant stages of method **200**. Certain embodiments comprise target design files of respective targets designed by embodiments of method **200**. Certain embodiments comprise metrology targets produced by corresponding embodiments of method **200** and/or metrology measurements thereof.

[0069] Method **200** may comprise designing a metrology target with supplementary target structures, e.g., as one or more supplementary layer(s) (stage **210**) and/or performing metrology measurements on respective metrology targets.

[0070] In certain embodiments, method **200** may comprise configuring the supplementary layer as an optical separation layer (stage **212**).

[0071] Method **200** may comprise incorporating a supplementary layer having a supplementary (possibly periodic or partially periodic) structure(s) between a bottom layer and a top layer of a metrology target (stage **220**), the supplementary structure configured to interact optically with at least one of a bottom periodic structure and a top periodic structure in the bottom and top layers, respectively (stage **230**).

[0072] In certain embodiments, method **200** may comprise designing the supplementary structure(s) to optically interact with bottom elements, produced in multi-patterning steps such as finFET elements (stage **232**). Method may comprise removing, selectively and periodically, specified finFET elements to yield a modified finFET layer (stage **235**) and deriving metrology measurements from the interaction of the supplementary structure with the modified finFET layer (stage **237**).

[0073] Method **200** may comprise introducing designed offsets between the top, supplementary and bottom structures (stage **240**) and using paired designed offsets with opposite signs (stage **245**). Method **200** may comprise designing a compound target comprising cells with different offsets between different layers

(stage **250**) and/or deriving metrology parameters from measurements of the cells (stage **255**). Method **200** may comprise designing and/or using three layered SCOL cells and two layered imaging cells, the latter lacking the top periodic structure (stage **260**). Method **200** may comprise combining two or more two-layered SCOL cells and/or two or more two-layered imaging cells, with different layer selections and different designed offsets (stage **270**).

[**0074**] In certain embodiments, method **200** may further comprise configuring the supplementary structure to yield a detectable Moiré pattern with at least one of the top and bottom periodic structures (stage **280**). Method **200** may comprise configuring the supplementary structure to yield detectable Moiré patterns with both the top and the bottom periodic structures (stage **285**), e.g., two Moiré patterns within three layered cells, each layer comprising unresolved periodic structures (stage **285**). The Moiré patterns may be measured with corresponding imaging cells (stage **287**) and/or with corresponding SCOL cells. Method **200** may comprise designing the supplementary structure to have a pitch slightly different from a common pitch of the top and bottom structures, to yield Moiré patterns of the same pitch with either layer (stage **290**), e.g., designing Moiré pattern generating cells as SCOL and/or imaging cells (stage **295**).

[**0075**] Method **200** may further comprise producing metrology targets using a (possibly modified) device production flow (stage **300**) and using device elements as part of the target. Method **200** may comprise utilizing the device production flow to introduce supplementary structure(s) to the metrology targets (stage **305**). Method **200** may use process steps of the standard device manufacturing process that are usually ignored in the metrology target design, resulting in the possibility to use without modification the device production flow.

[**0076**] For example, method **200** may comprise producing the supplementary layer by one or more hard mask exposures (stage **307**). Method **200** may comprise depositing two or more substances to generate the supplementary structure (stage **310**). Method **200** may further comprise modifying parameters of supplementary structure elements using recurring etching and deposition (stage **315**). In certain embodiments, the supplementary structure may be configured to

yield a detectable Moiré pattern with at least one of the top and bottom periodic structures.

[0077] Method **200** may comprise deriving imaging and/or SCOL metrology measurements from the produced targets (stage **320**). Method **200** may further comprise resolving phase information from Moiré pattern measurements of the target (stage **325**), e.g., by interfering a SCOL first order signal from the target, by at least one of: manipulating the illumination, interfering the signal with a reference beam and interfering first with minus first order signals (stage **330**) or possibly with the zeroth order signal.

[0078] In certain embodiments, method **200** comprises depositing an optical separation layer configured to block optical interaction with structures below the deposited layer, and producing a metrology target above the optical separation layer.

[0079] 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.

[0080] 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.

[0081] 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.

[0082] 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.

[0083] 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.

[0084] 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.

[0085] 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 metrology target comprising, between a bottom layer and a top layer each having a corresponding periodic structure, at least one supplementary structure configured to interact optically with at least one of the bottom periodic structure and the top periodic structures.
2. The metrology target of claim 1, wherein the bottom layer comprises a plurality of periodic multiply patterned elements, with which the at least one supplementary structure is configured to interact optically.
3. The metrology target of claim 2, wherein the multiply patterned elements comprise recurring sets of corresponding elements, and wherein the target comprises multiple cells, each lacking a different one of the elements in the recurring set.
4. The metrology target of claim 1, wherein the bottom and top periodic structures have a same pitch and wherein the at least one supplementary structure has a pitch that is different from the same pitch to an extent that generates a detectable Moiré pattern between the periodic structures.
5. The metrology target of claim 4, configured as an imaging target having at least a first cell with the top and supplementary structures and a second cell with the bottom and supplementary structures.
6. The metrology target of claim 4, configured as scatterometry overlay (SCOL) target comprising the at least one supplementary structure with the bottom and top layers in at least one cell.
7. The metrology target of claim 1, comprising at least two SCOL cells having opposite designed offsets between the top periodic structure and the bottom periodic structure and at least one imaging cell lacking the top periodic structure and having at least three supplementary structures, two of which having opposite offsets and one of which having no offset of the supplementary structure with respect to the bottom periodic structure.
8. The metrology target of claim 1, comprising at least one imaging cell having at least three supplementary structures, two of which having opposite offsets and one of

which having no offset of the supplementary structure with respect to the bottom periodic structure.

9. The metrology target of claim 1, comprising at least two imaging cells, each having at least three supplementary structures, two of which having opposite offsets and one of which having no offset of the supplementary structure with respect to the bottom periodic structure, wherein in one of the imaging cells the supplementary structure is configured to form a detectable Moiré pattern with the bottom periodic structure and in another one of the imaging cells the supplementary structure is configured to form a detectable Moiré pattern with the top periodic structure.
10. The metrology target of claim 1, comprising an array of imaging cells, each cell having different combinations of designed offsets between the at least one supplementary structure and the top and bottom periodic structures.
11. The metrology target of claim 10, wherein the array comprises at least nine cells with all combinations of opposite and zero designed offsets between the structures.
12. The metrology target of claim 10, wherein the array comprises at least five cells, each cell having no offset or a single one of opposite offsets between the bottom periodic structure and one of the supplementary structure and the top periodic structure.
13. The metrology target of claim 1, comprising at least two imaging cells, each having at least three supplementary structures, two of which having opposite offsets and one of which having no offset of the supplementary structure with respect to the bottom periodic structure, wherein in one of the imaging cells the offset is between the supplementary structure and the bottom periodic structure and in another one of the imaging cells offset is between the top periodic structure and the bottom periodic structure.
14. The metrology target of claim 1, comprising at least two SCOL cell pairs having opposite designed offsets, one pair having the designed offsets between the top periodic structure and the bottom periodic structure, and another pair lacking the top periodic structure and having the designed offsets between the supplementary structure and the bottom periodic structure.

15. A method comprising incorporating at least one supplementary structure between a bottom layer and a top layer of a metrology target, the at least one supplementary structure configured to interact optically with at least one of a bottom periodic structure and a top periodic structure in the bottom and top layers, respectively.
16. The method of claim 15, further comprising designing the supplementary structure to interact optically with bottom multiply patterned elements.
17. The method of claim 16, further comprising removing, selectively and periodically, specified multiply patterned elements to yield a modified multiply patterned layer and deriving metrology measurements from the interaction of the at least one supplementary structure with the modified multiply patterned layer.
18. The method of claim 15, further comprising introducing designed offsets between the at least one supplementary structure and the top and bottom periodic structures and using paired designed offsets with opposite signs.
19. The method of claim 15, further comprising designing three layered SCOL cells and two layered imaging cells, the latter lacking the top periodic structure.
20. The method of claim 15, further comprising configuring the at least one supplementary structure to yield a detectable Moiré pattern with at least one of the top and bottom periodic structures.
21. The method of claim 20, further comprising configuring the at least one supplementary structure to yield detectable Moiré patterns with both the top and the bottom periodic structures.
22. The method of claim 15, further comprising producing the at least one supplementary structure within a device production process, by one or more hard mask exposures.
23. The method of claim 15, further comprising depositing two or more substances to generate the at least one supplementary structure.
24. The method of claim 22, further comprising modifying parameters of supplementary structure elements using recurring etching and deposition.
25. The method of claim 15, further comprising performing metrology measurements on the metrology target.

26. The method of claim 25, wherein the at least one supplementary structure is configured to yield a detectable Moiré pattern with at least one of the top and bottom periodic structures, the method further comprising resolving phase information from Moiré pattern measurements of the target.
27. The method of claim 26, wherein the phase information is retrieved by interfering a SCOL first order signal from the target, by at least one of: manipulating the illumination, interfering the signal with a reference beam and interfering plus first with minus first order signals.
28. A method comprising:
depositing an optical separation layer configured to block optical interaction with structures below the deposited layer, and
producing a metrology target above the optical separation layer.
29. A metrology target produced by claim 15.
30. A metrology target produced by claim 28.
31. A metrology optical system, comprising an illumination source, a beam splitter and a detector and configured to illuminate a wafer with radiation from the illumination source directed via the beam splitter onto the wafer, the beam splitter further directing a reflected signal to the detector, the optical system further comprising at least one of an apodizer and a field stop configured to interfere a zeroth order reflected diffraction signal with a first order reflected diffraction signal at a pupil plane in which the detector is located.
32. A metrology optical system, comprising an illumination source, a beam splitter and a detector and configured to illuminate a wafer with radiation from the illumination source directed via the beam splitter onto the wafer, the beam splitter further directing a reflected signal to the detector, the optical system further comprising an optical assembly configured to interfere a part of the reflected signal with a mirror image thereof to yield, at a pupil plane in which the detector is located, an interference of a plus first order reflected diffraction signal with a minus first order reflected diffraction signal.
33. A metrology optical system, comprising an illumination source, a beam splitter and a detector and configured to illuminate a wafer with radiation from the illumination

source directed via the beam splitter onto the wafer, the beam splitter further directing a reflected signal to the detector, the optical system further comprising an optical assembly configured to interfere a part of the illuminated radiation with the collected signal to derive phase information of the reflected signal.

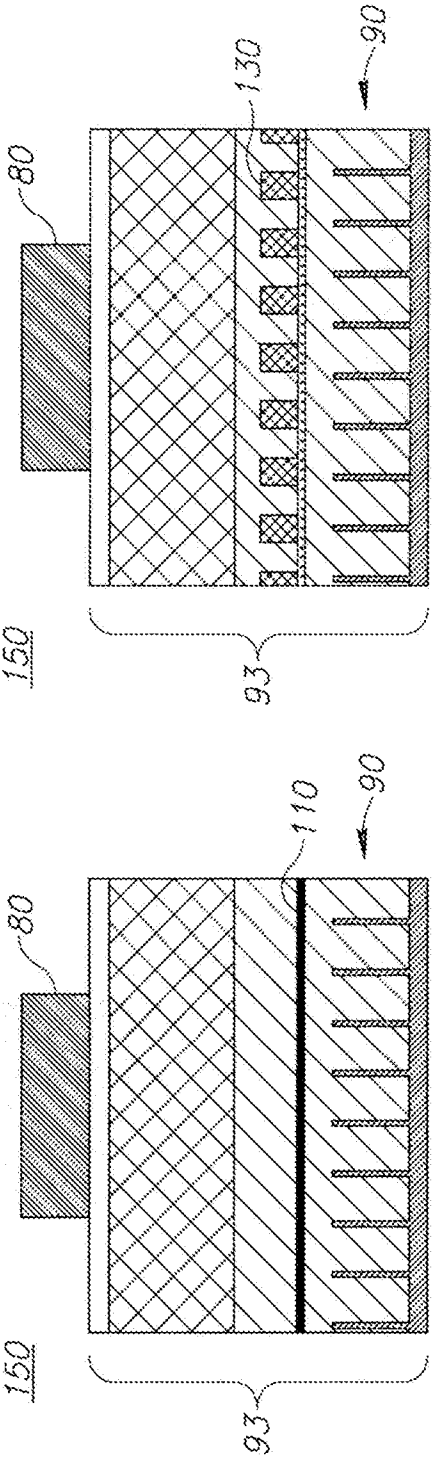


Figure 1A

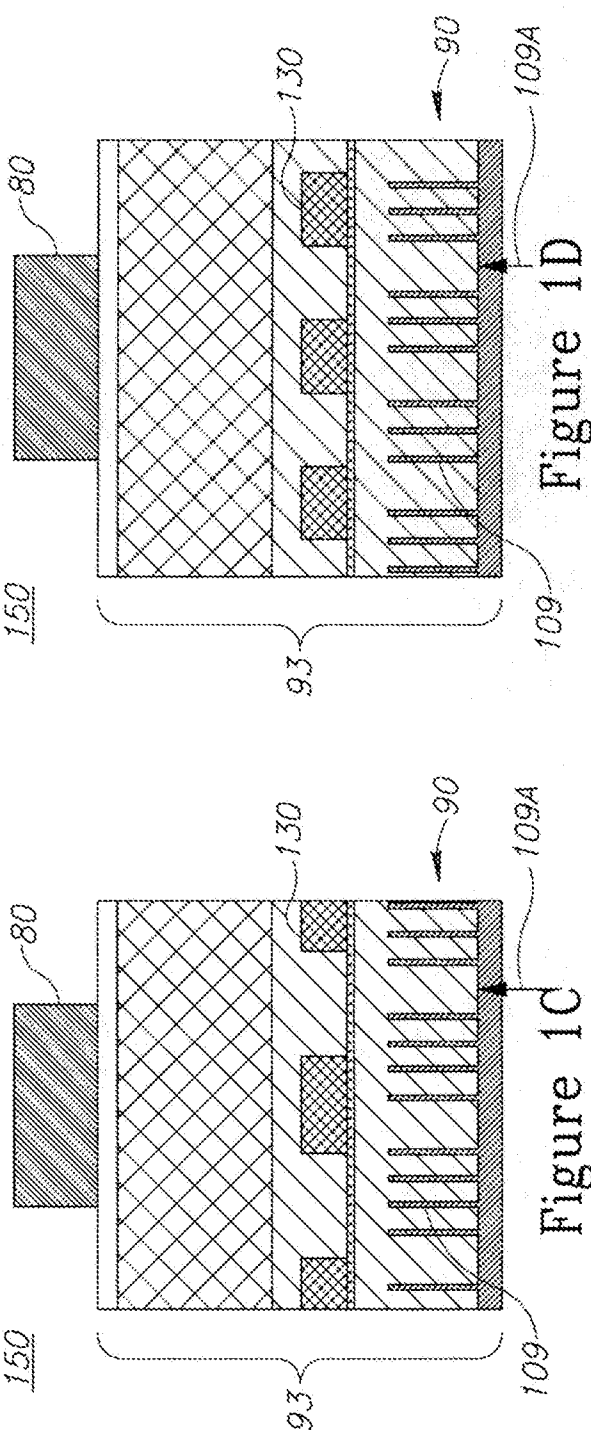


Figure 1B

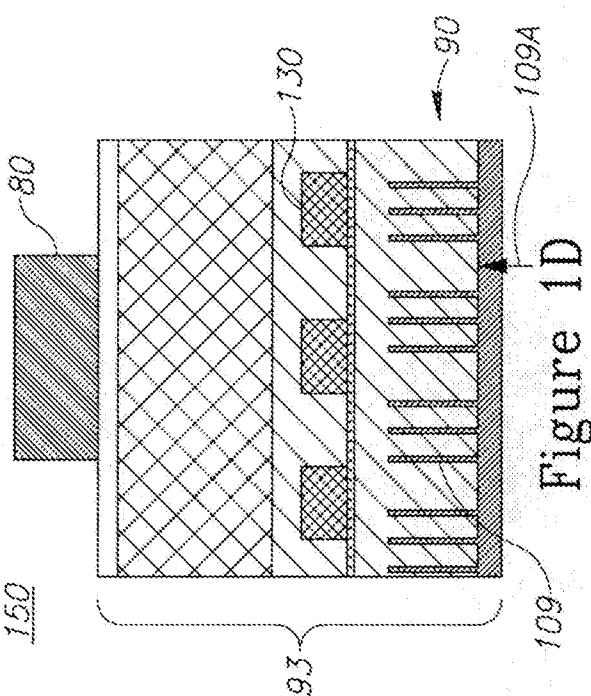


Figure 1C

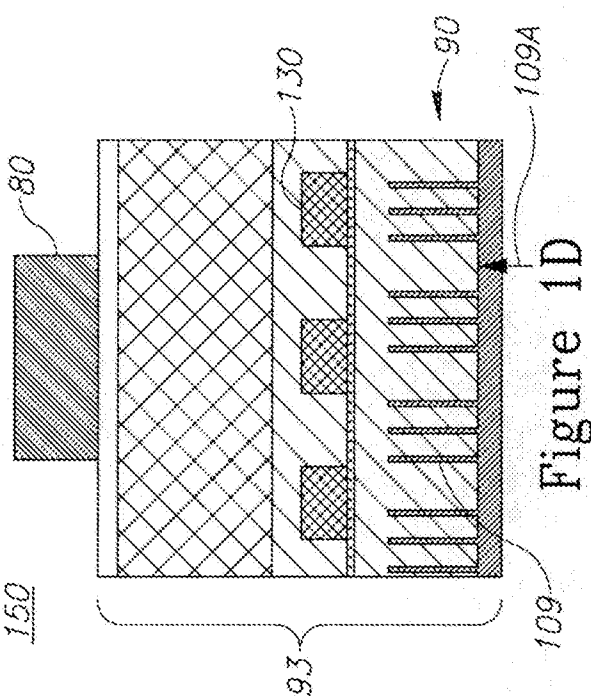


Figure 1D

150

151
152

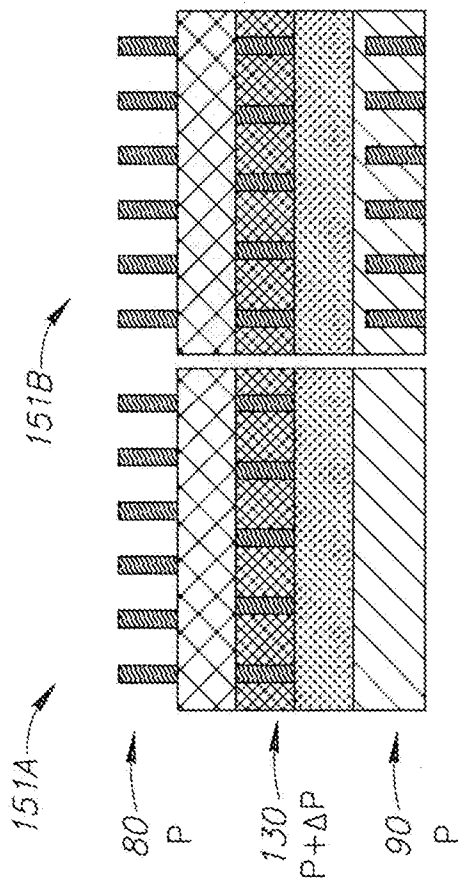


Figure 2A

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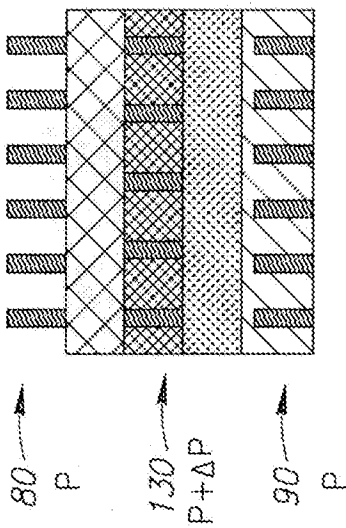


Figure 2B

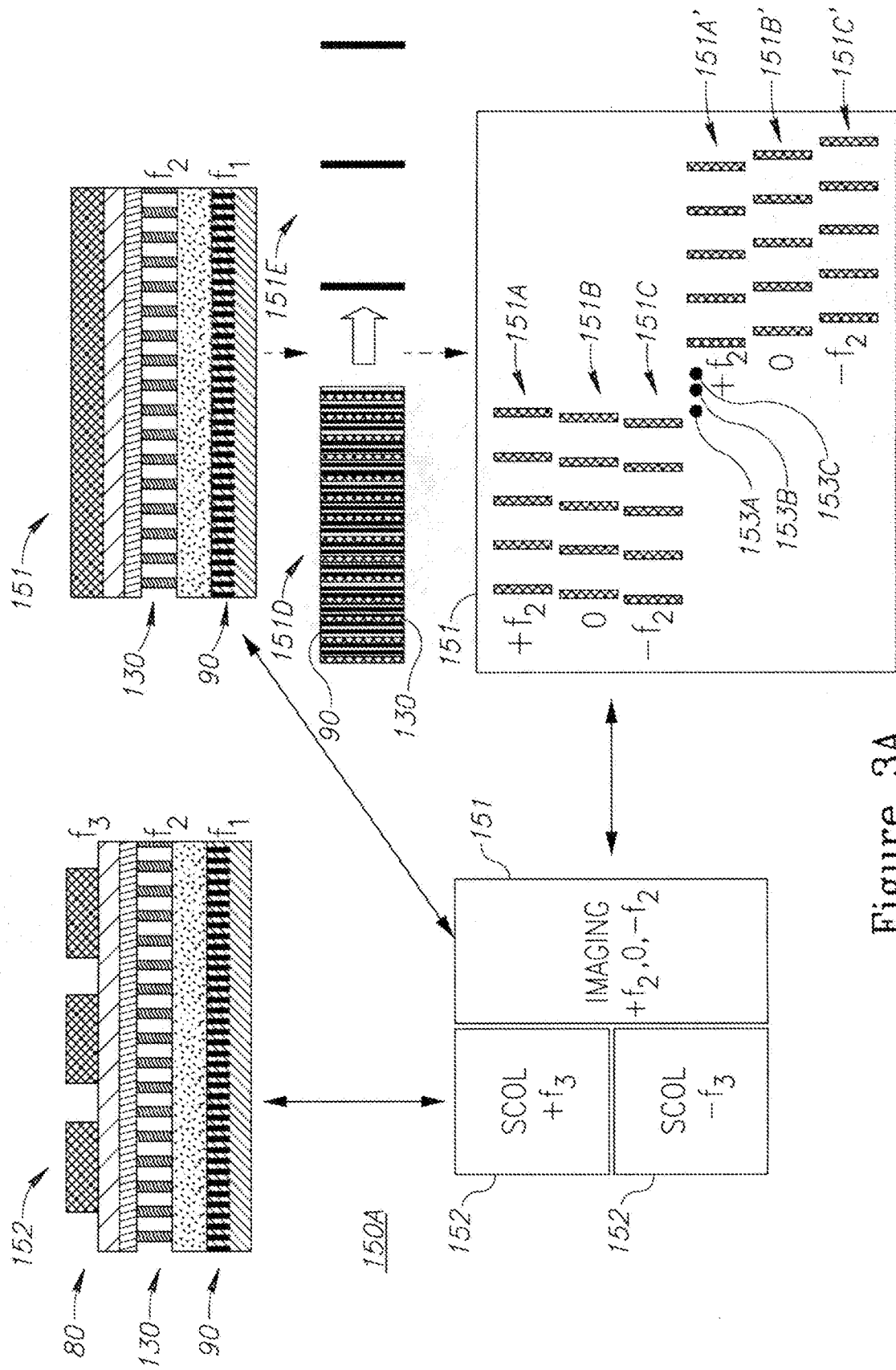
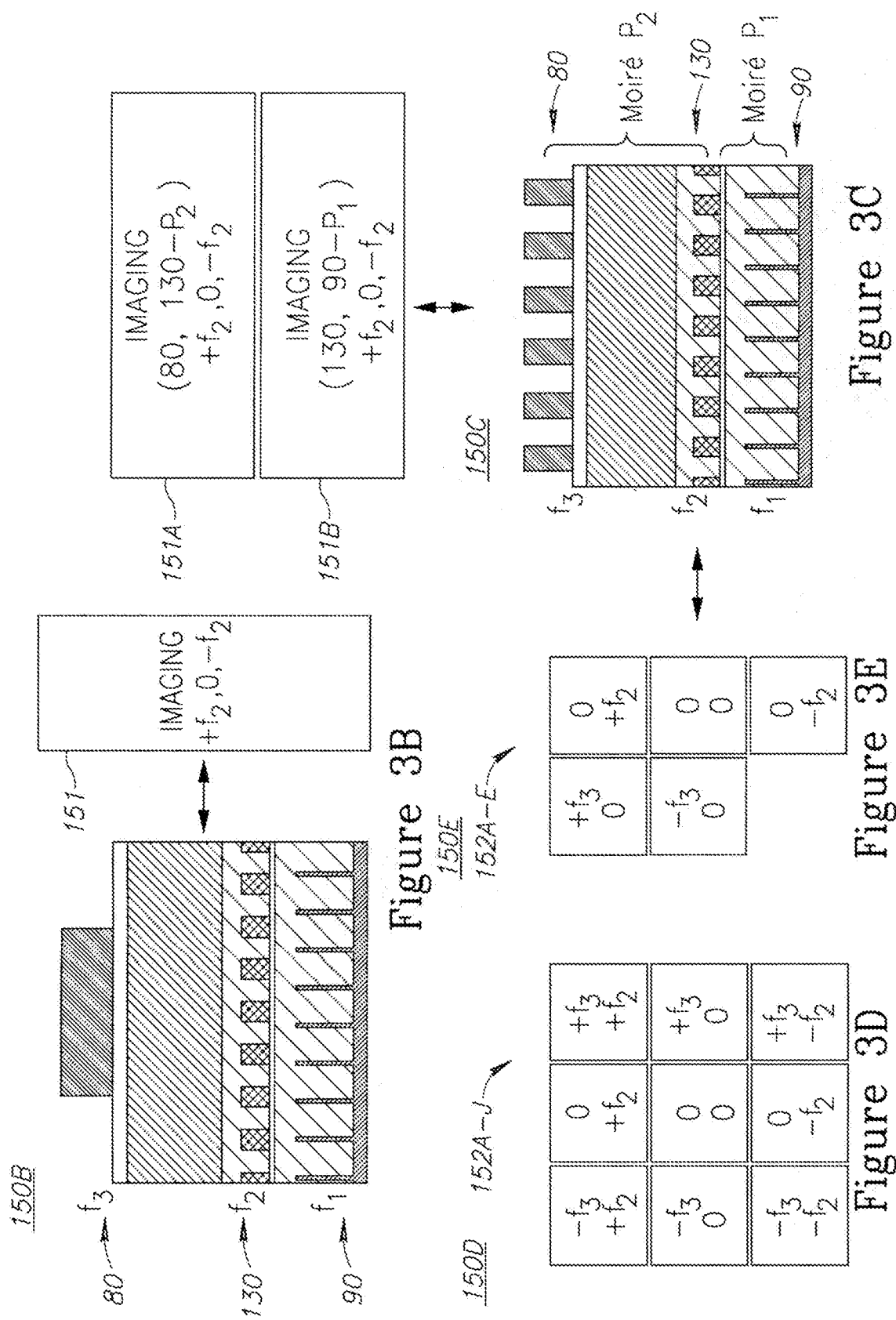
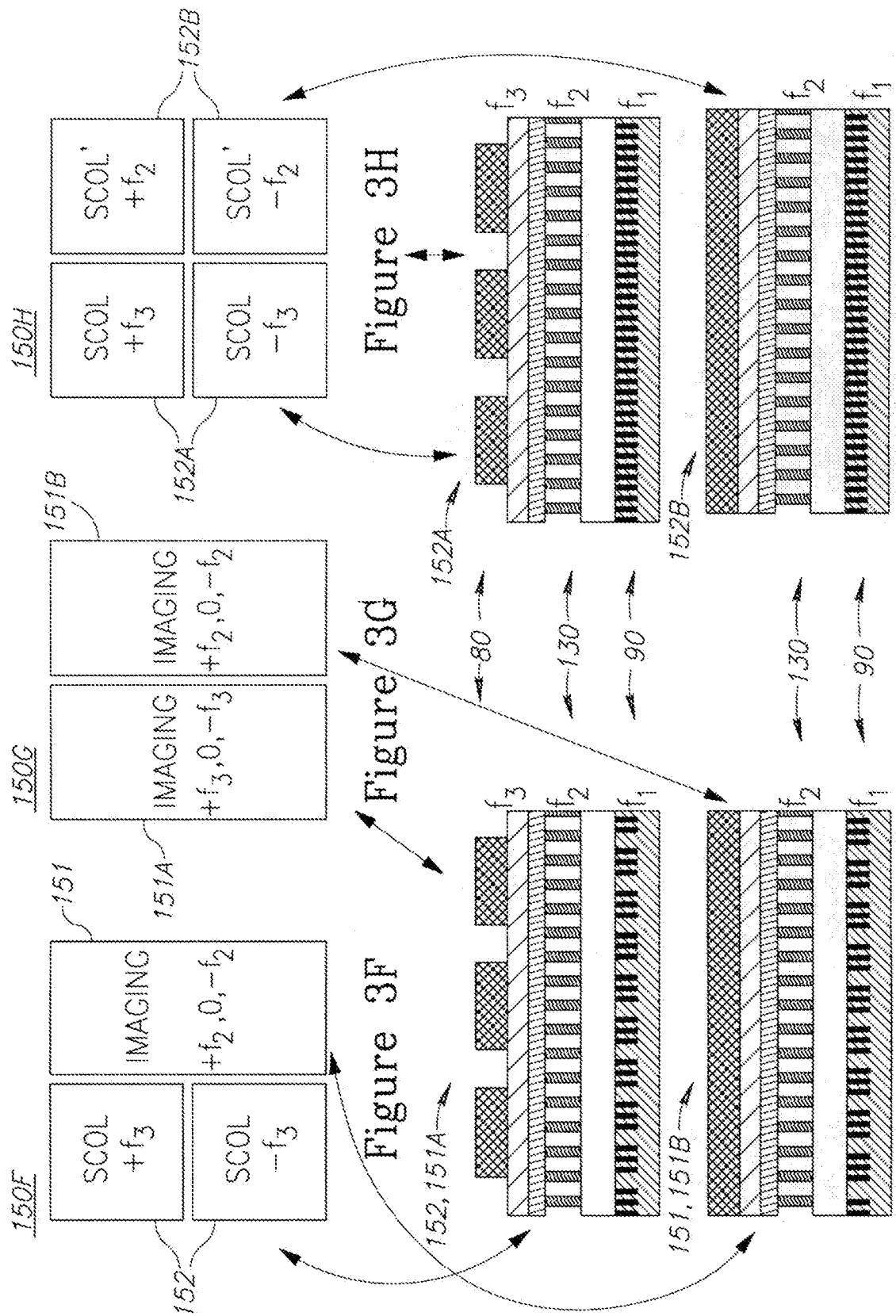


Figure 3A





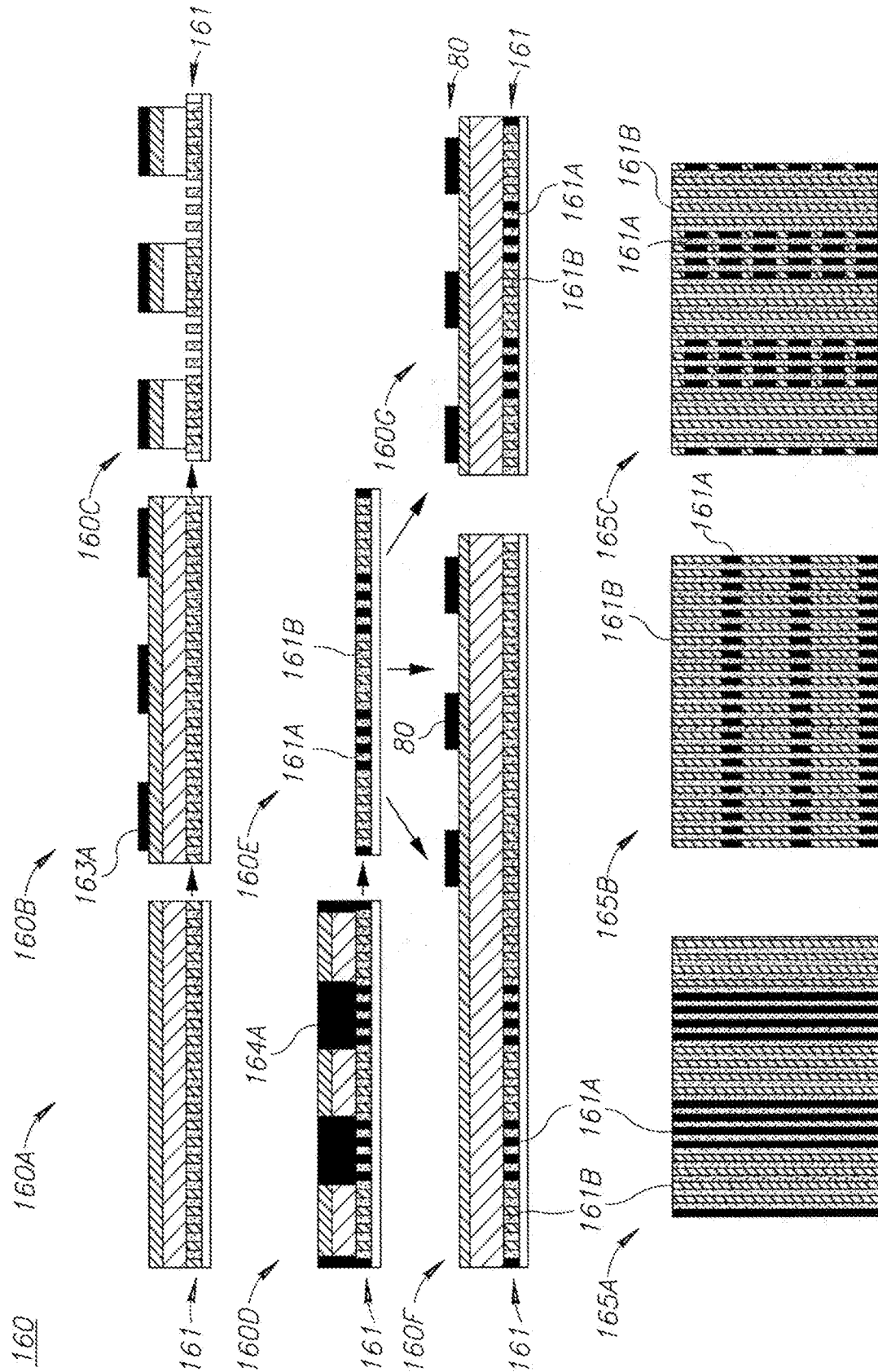


Figure 4A

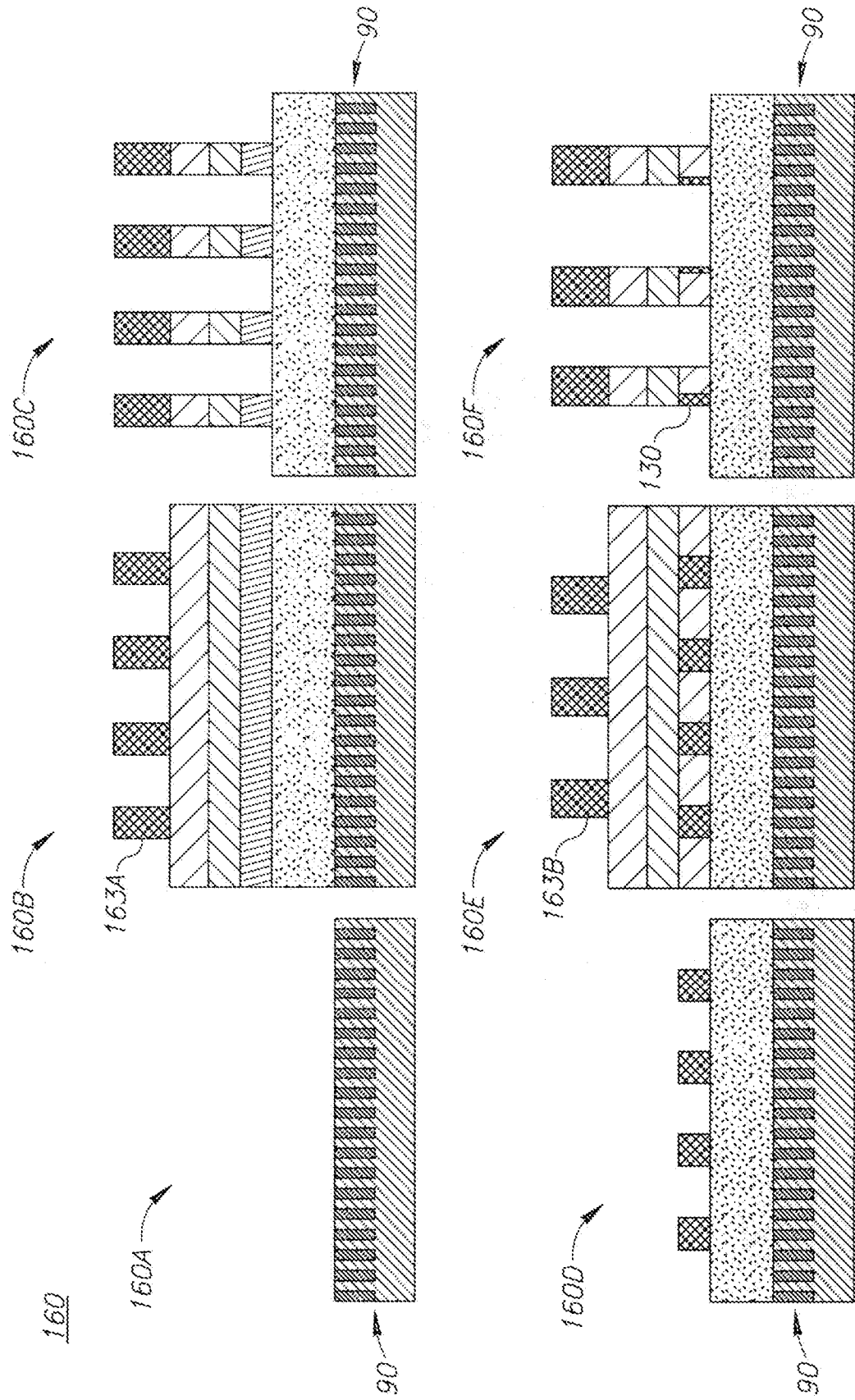


Figure 4B

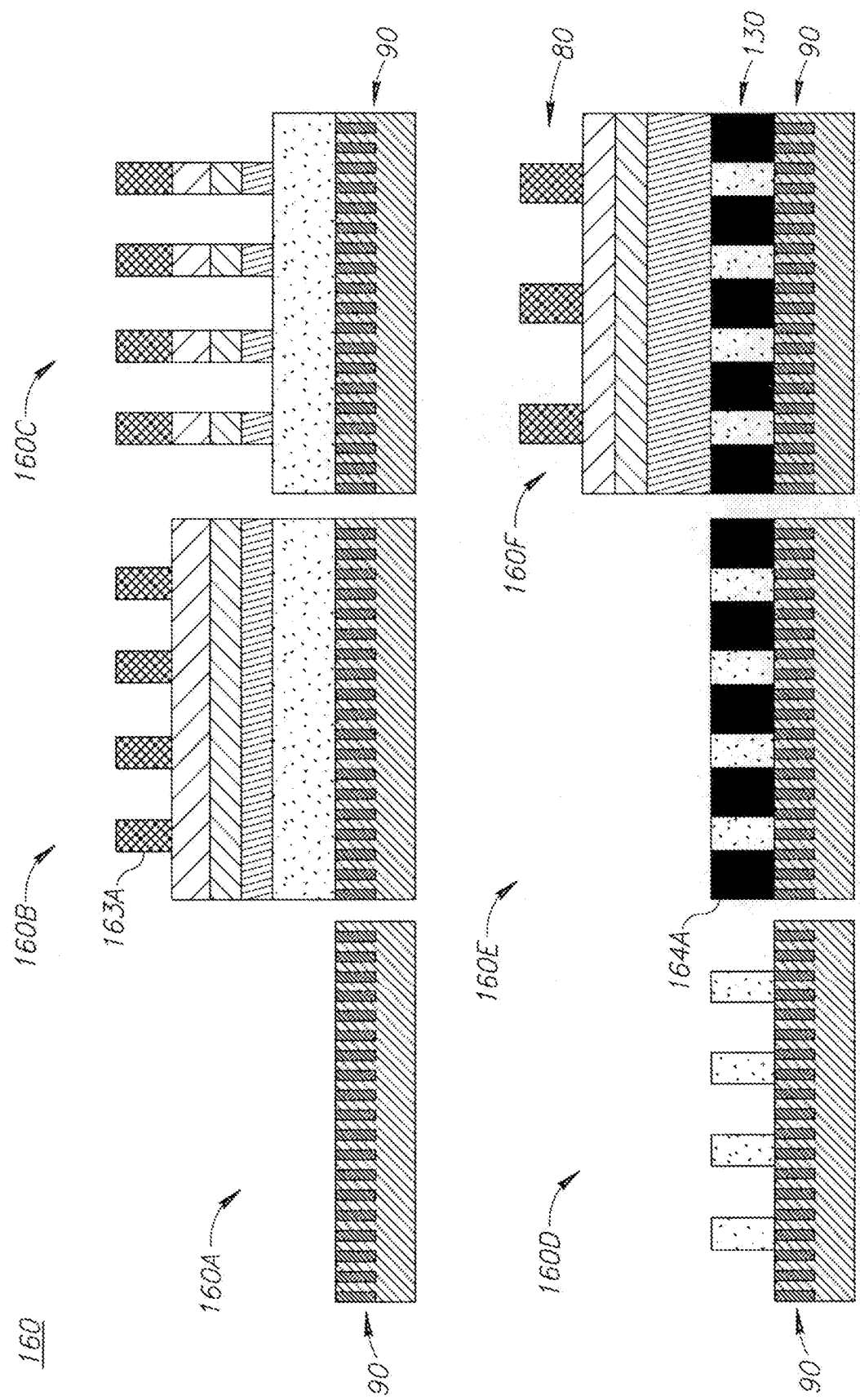


Figure 4C

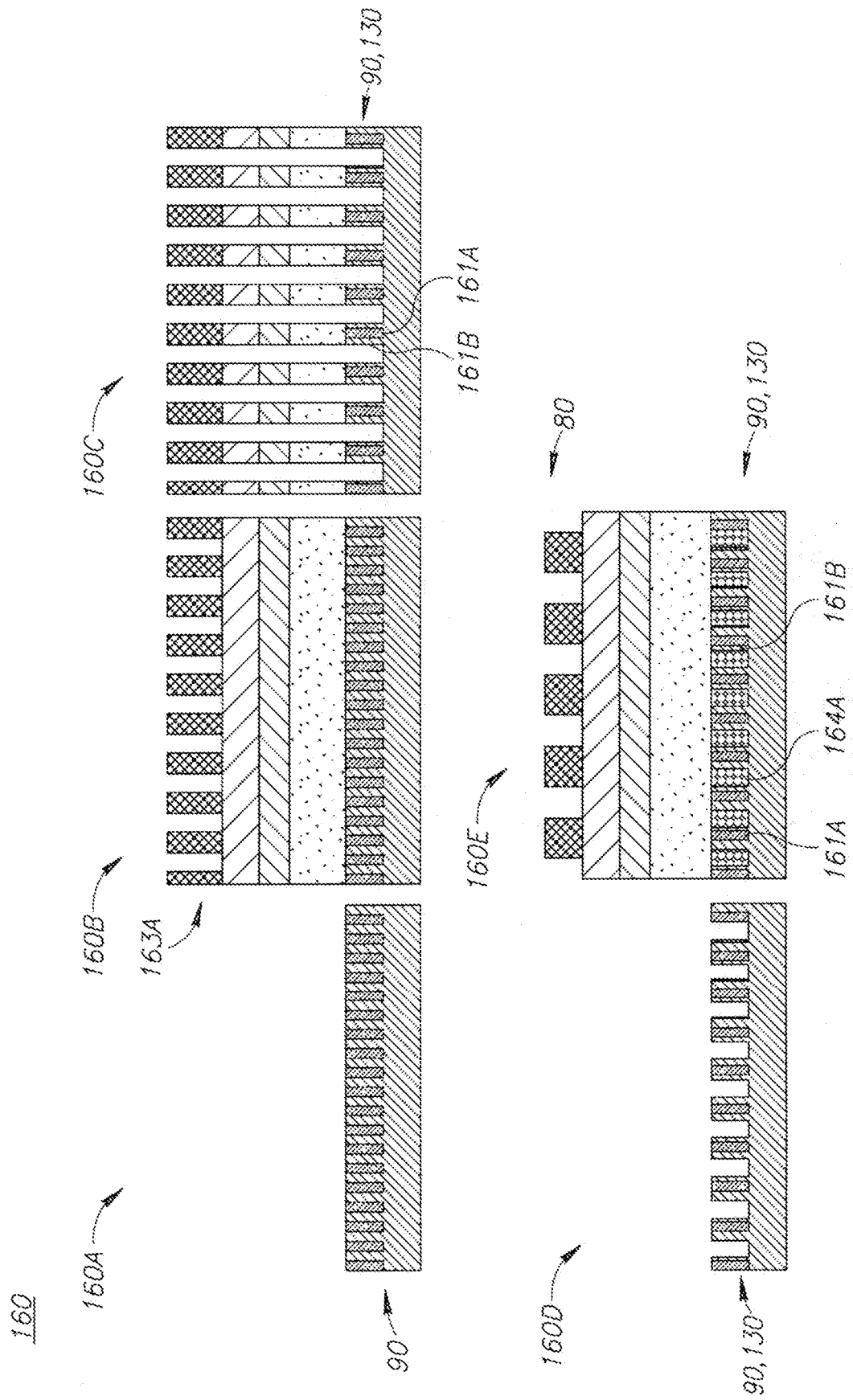


Figure 4D

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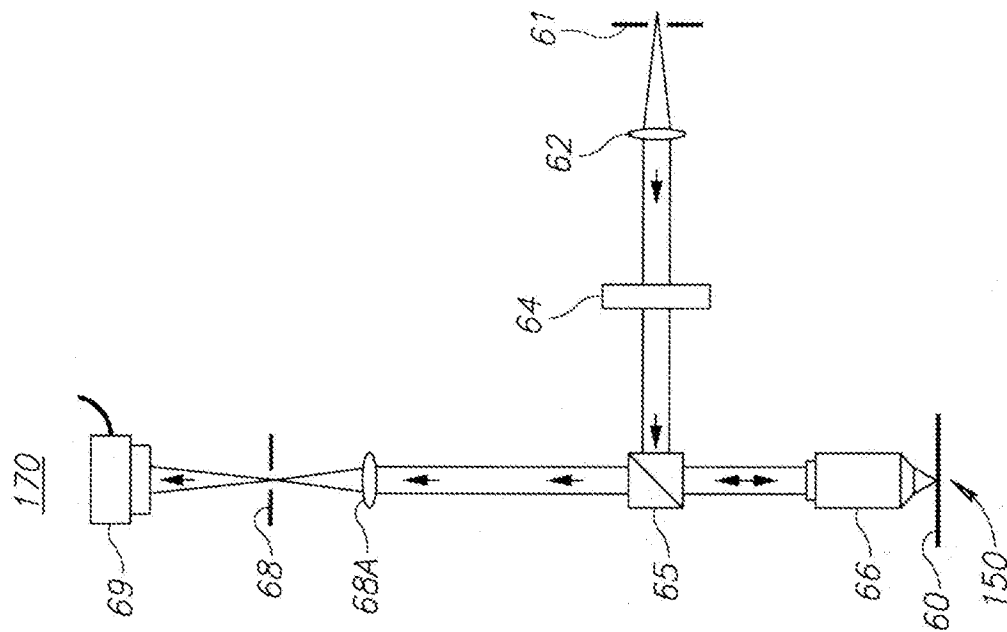


Figure 5B

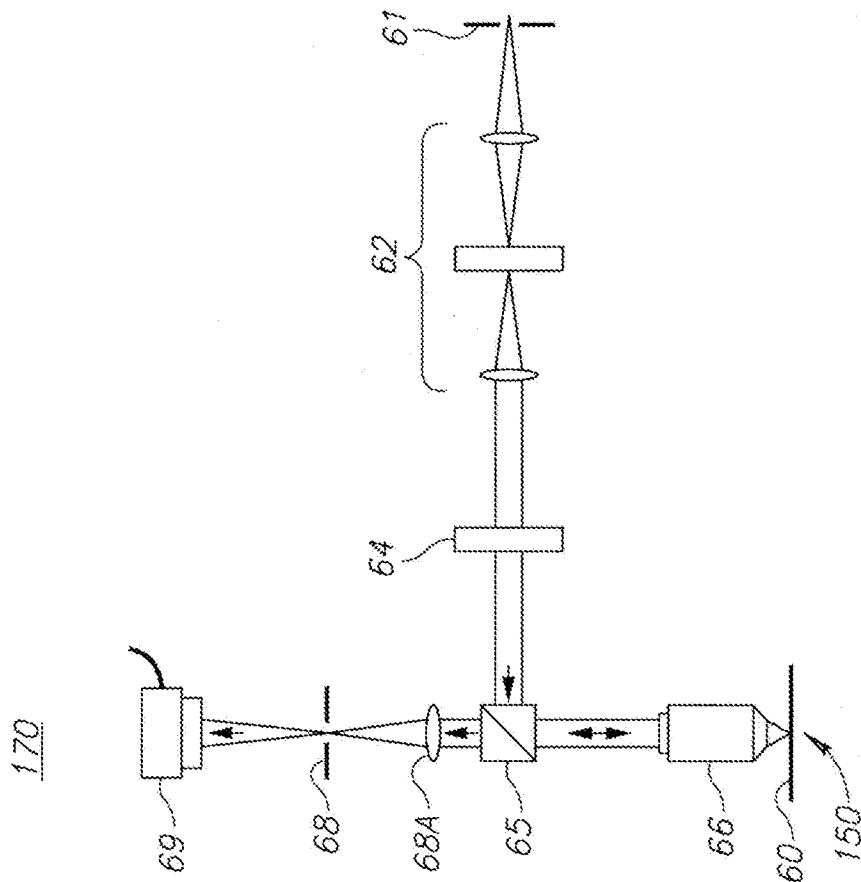
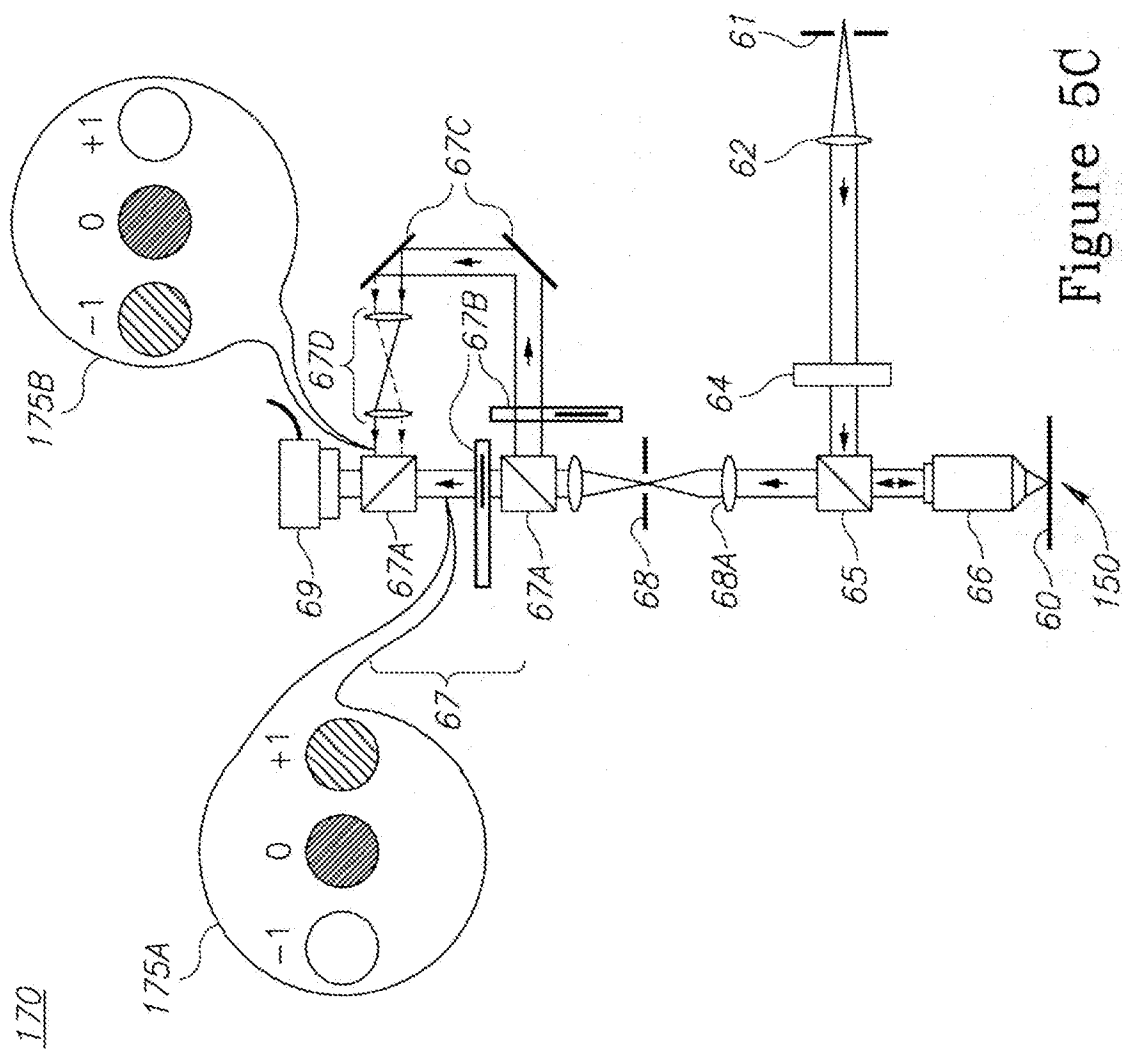


Figure 5A



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170

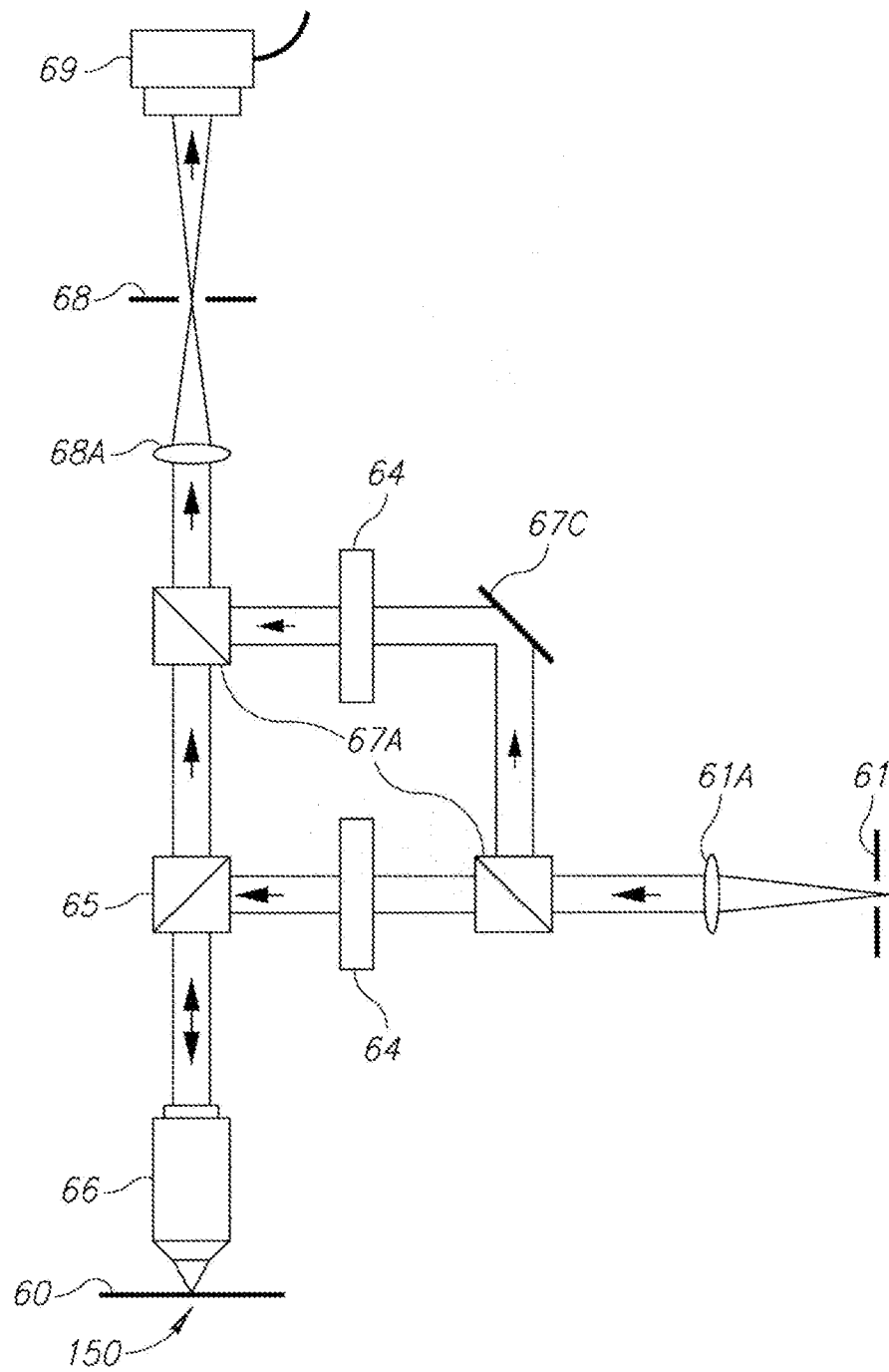
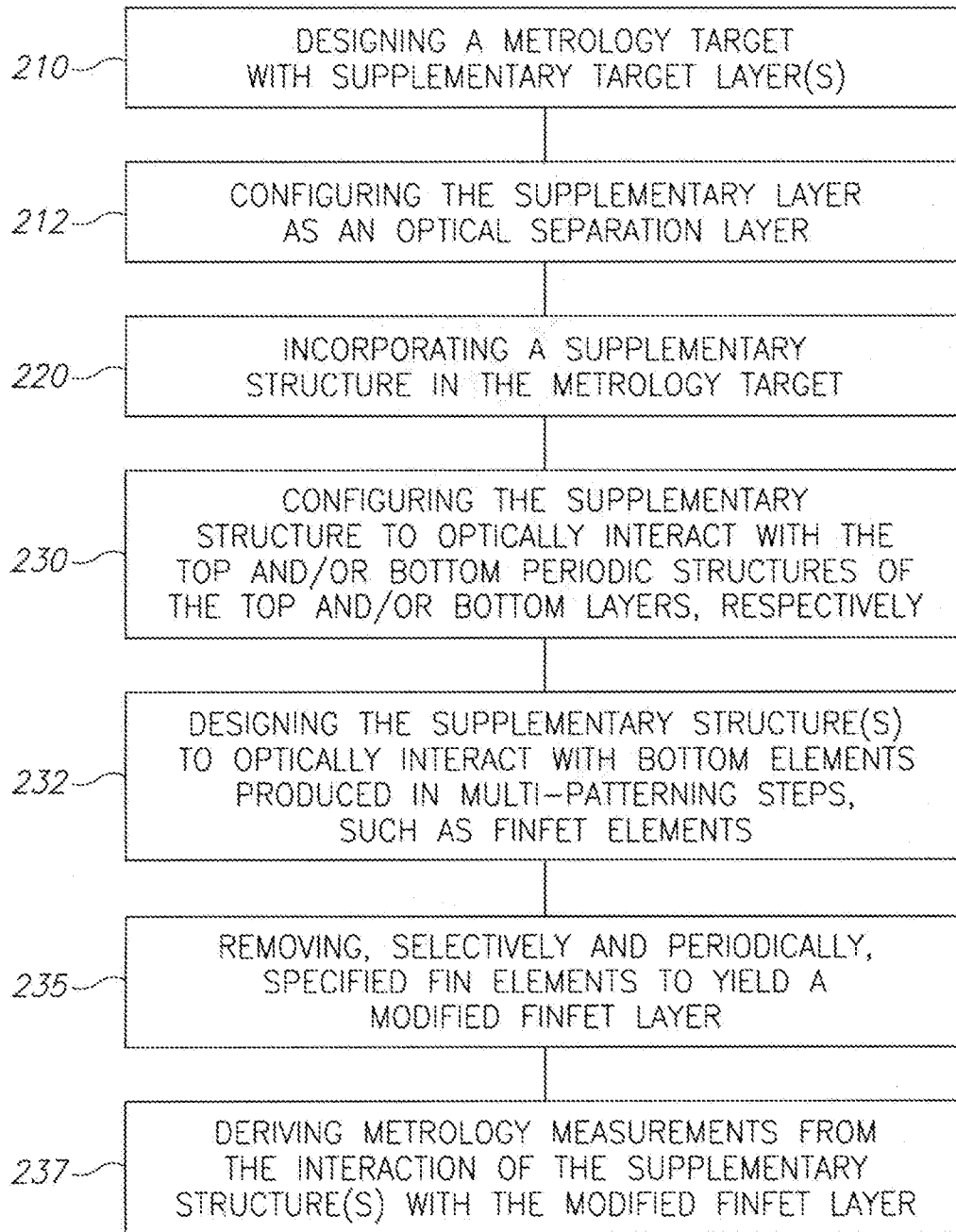


Figure 5D

13/16200**Figure 6**

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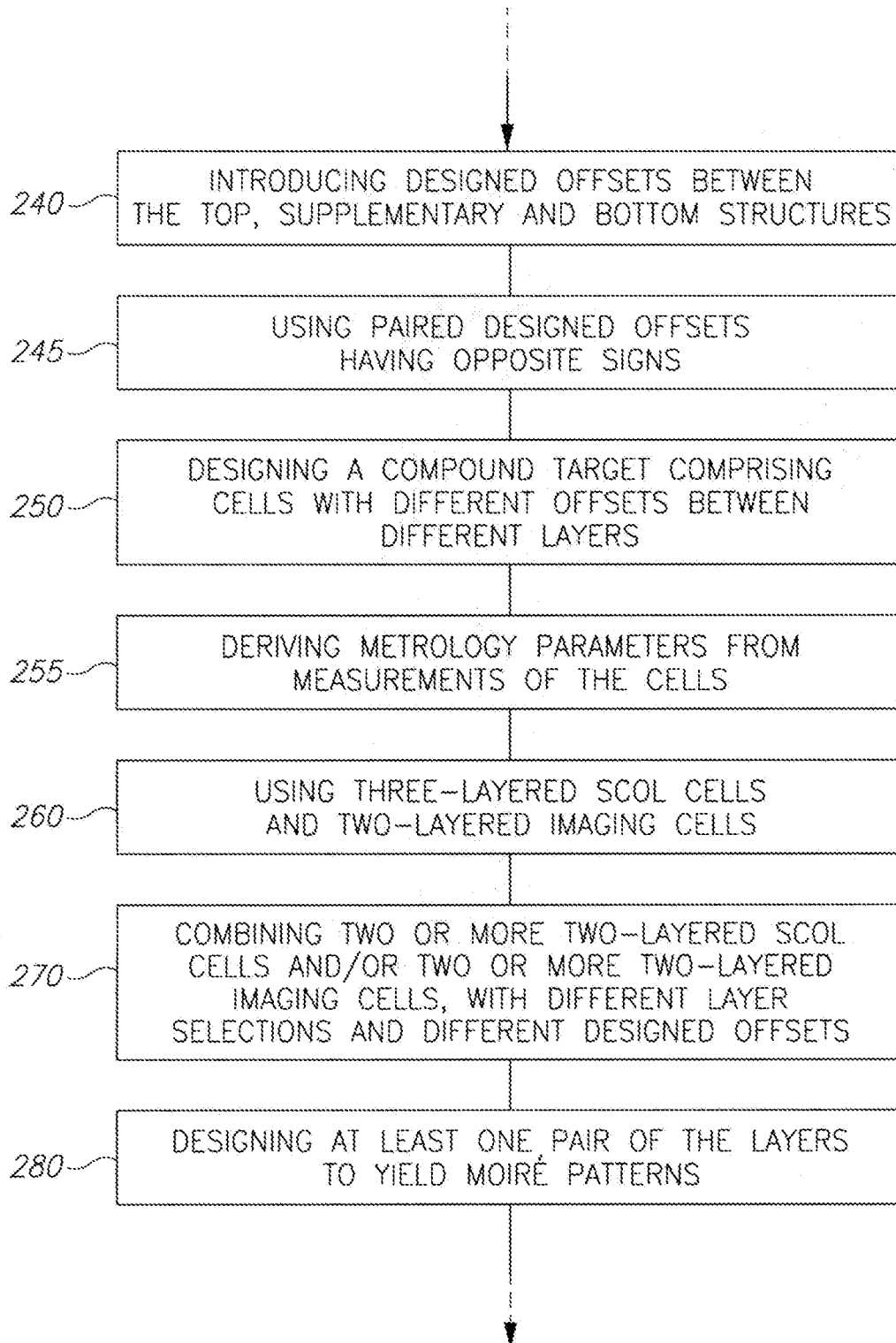


Figure 6 (cont. 1)

15/16

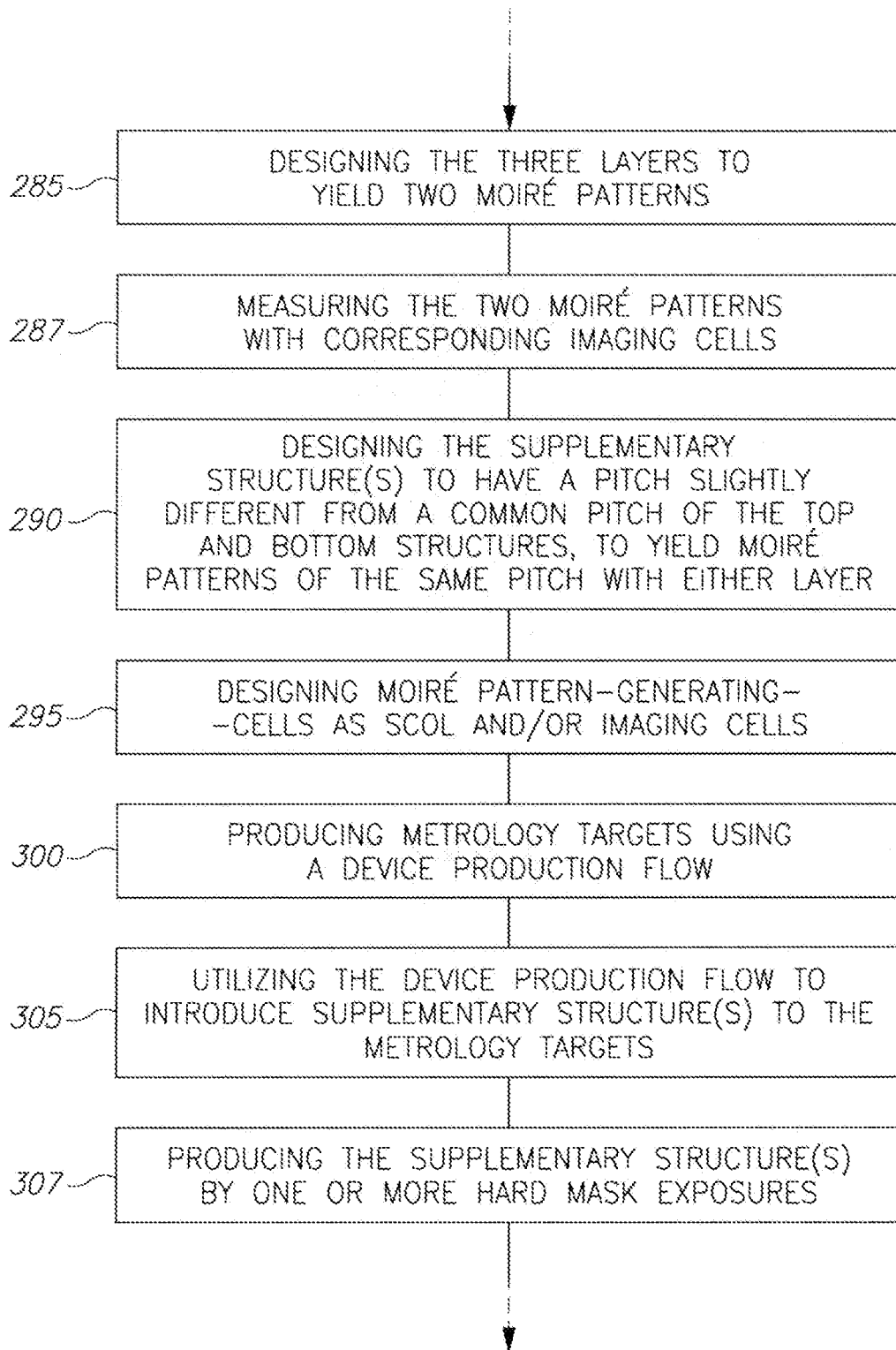


Figure 6 (cont. 2)

16/16

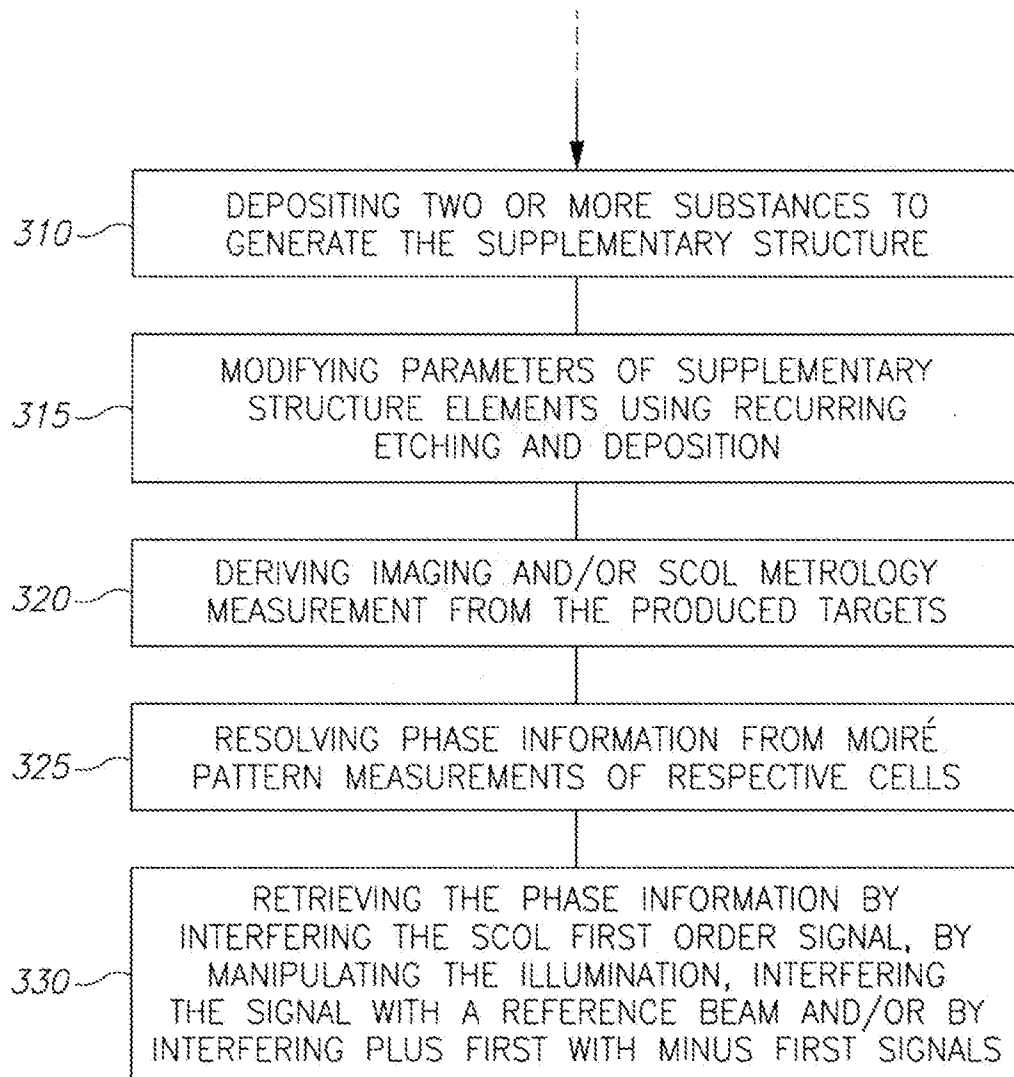


Figure 6 (cont. 3)

A. CLASSIFICATION OF SUBJECT MATTER**G01B 11/25(2006.01)i, G02B 27/60(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)

G01B 11/25; G06F 17/50; G01B 11/02; G01N 21/41; H05K 3/00; G01N 21/956; G01B 11/27; G03F 7/20; G02B 27/60

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: illumination, layer, metrology target, periodic structure, supplementary structure, cell, pupil plane, apodizer

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015-0233818 A1 (KLA-TENCOR CORPORATION) 20 August 2015 See paragraphs [0027]-[0035], [0046], [0052], [0054], claims 3, 11, 32, 33, and figures 1, 5, 8, 9.	1, 2, 4, 15-18, 20-26, 28-30
Y		3, 5-14, 19, 27, 31-33
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Further documents are listed in the continuation of Box C.



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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, Chang Ho

Telephone No. +82-42-481-8288



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