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(54) **DIE SYSTEM AND METHOD OF COMPARING ALIGNMENT VECTORS**

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G06T 7/00 (2017.01)

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(58) **Field of Classification Search**
CPC G06T 7/0006; G06T 7/33
See application file for complete search history.

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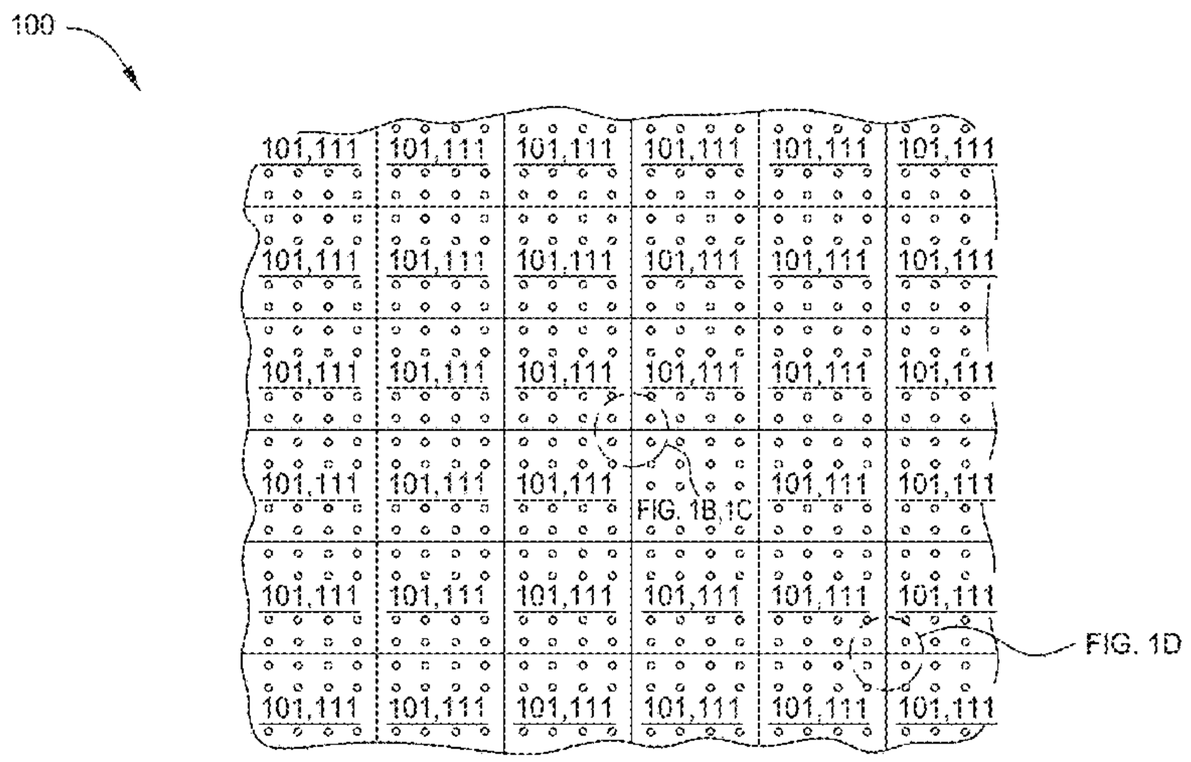
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(57) **ABSTRACT**

Embodiments of the present disclosure include a die system and a method of comparing alignment vectors. The die system includes a plurality of dies arranged in a desired pattern. An alignment vector, such as a die vector, can be determined from edge features of the die. The alignment vectors can be compared to other dies or die patterns in the same system. A method of comparing dies and die patterns includes comparing die vectors and/or pattern vectors. The comparison between alignment vectors allows for fixing the die patterns for the next round of processing. The methods provided allow accurate comparisons between as-deposited edge features, such that accurate stitching of dies can be achieved.

19 Claims, 6 Drawing Sheets



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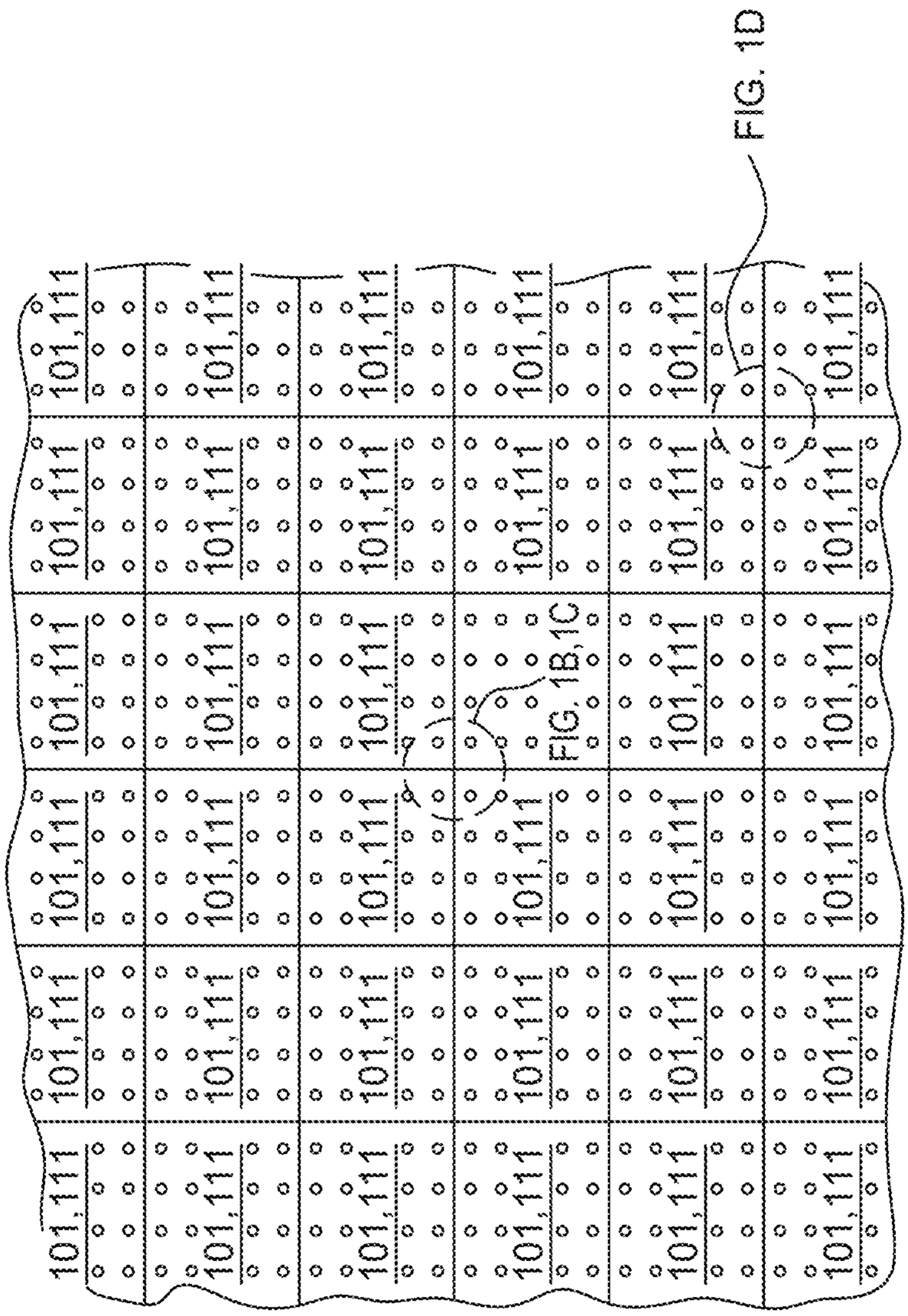


FIG. 1A

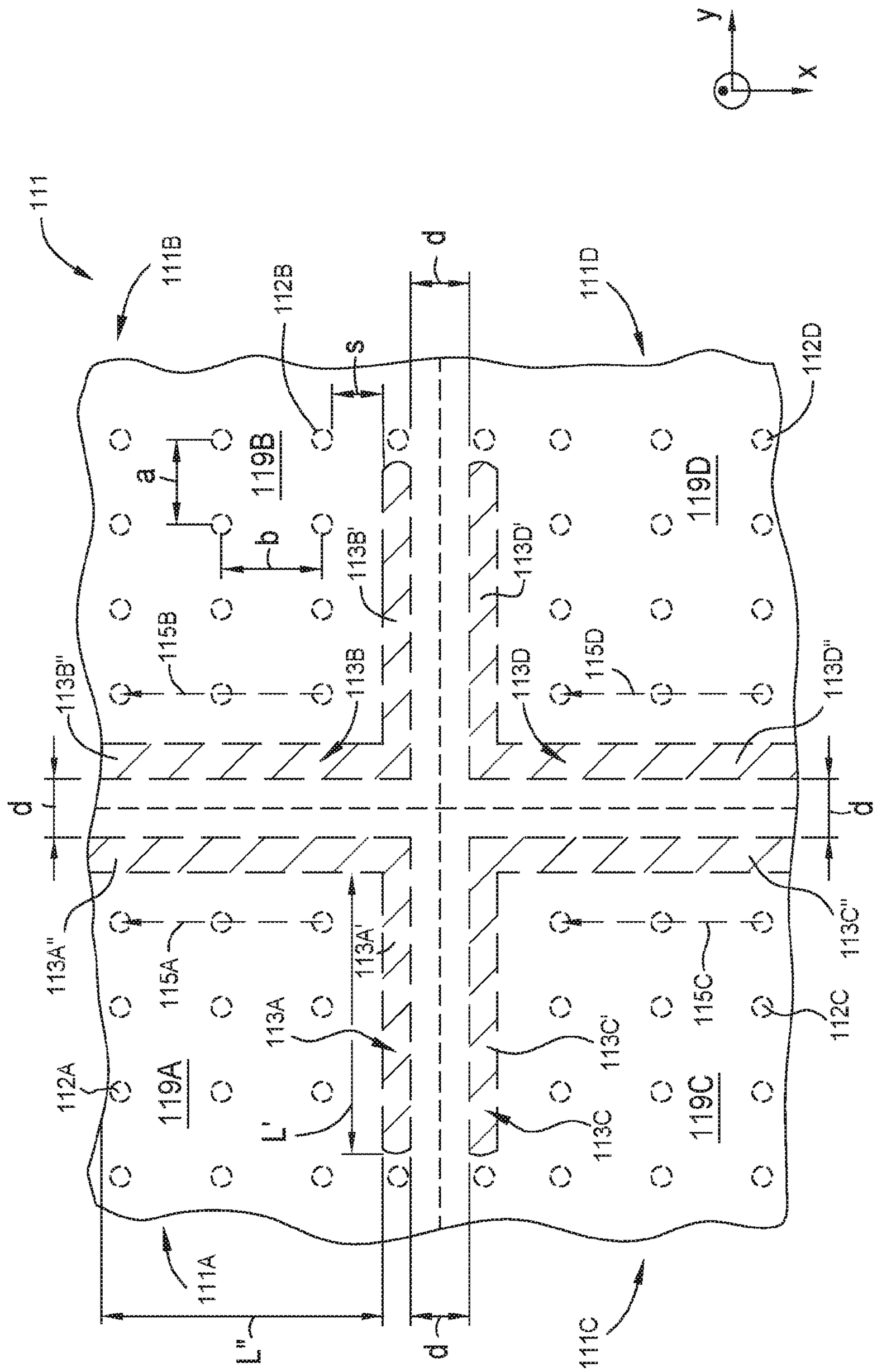

y
x
111
111B
112B
s
111D
112D
a
b
119B
119D
113B'
113D'
113B"
115B
113B
113D
115D
113D"
d
113A"
115A
113A'
113A
113C"
112A
119A
L'
113C'
113C
119C
115C
112C
111A
L"
d
111C

FIG. 1B

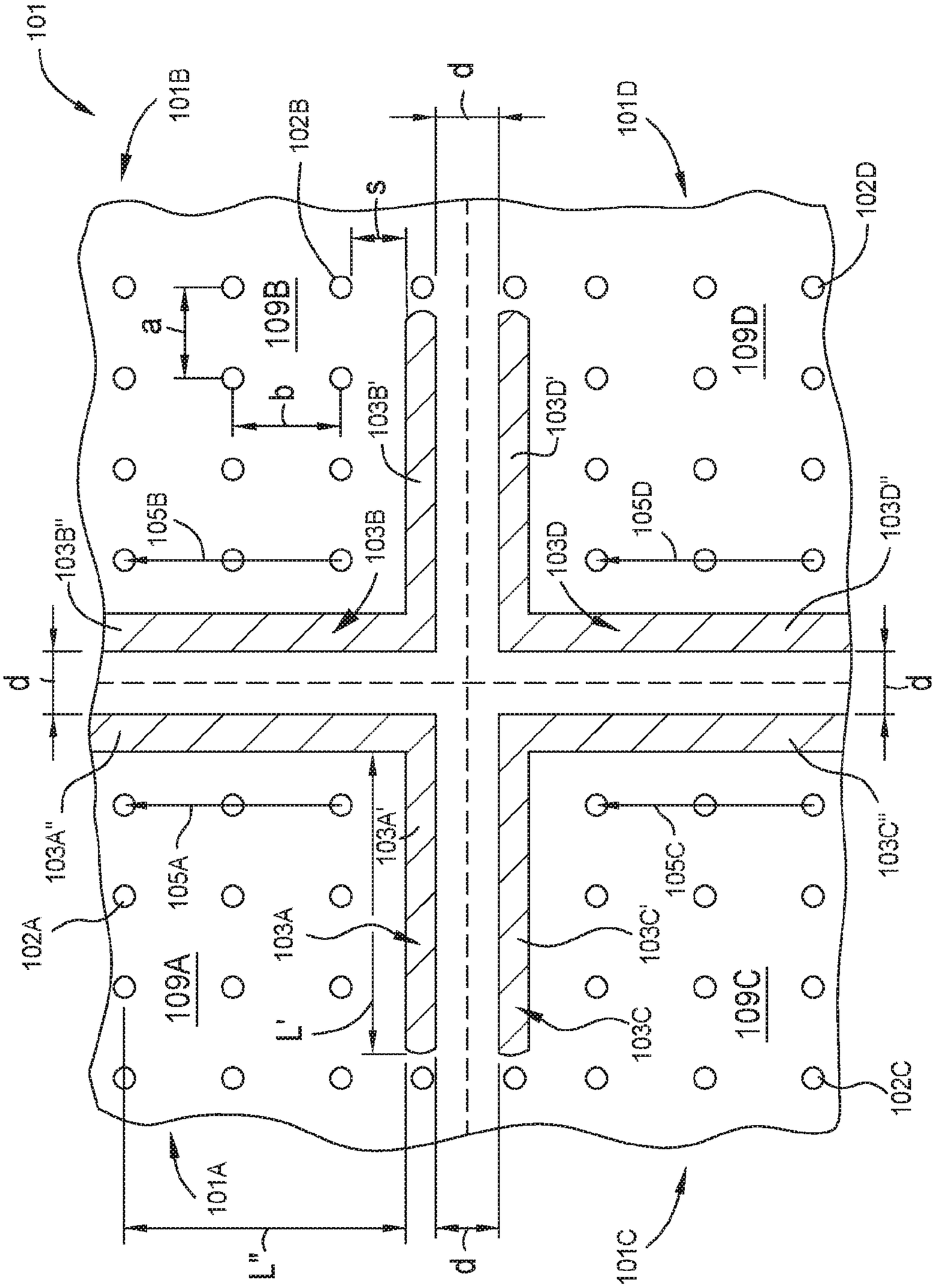

θAA'
105A
y
x
101
101B
102B
s
d
101D
102D
a
109B
b
103B'
103D'
109D
105B
103B
105D
103B"
103D
103D"
d
103A"
105A
102A
109A
103A
103A'
L'
103C
103C'
105C
103C"
109C
102C
101A
L"
d
101C

FIG. 1C

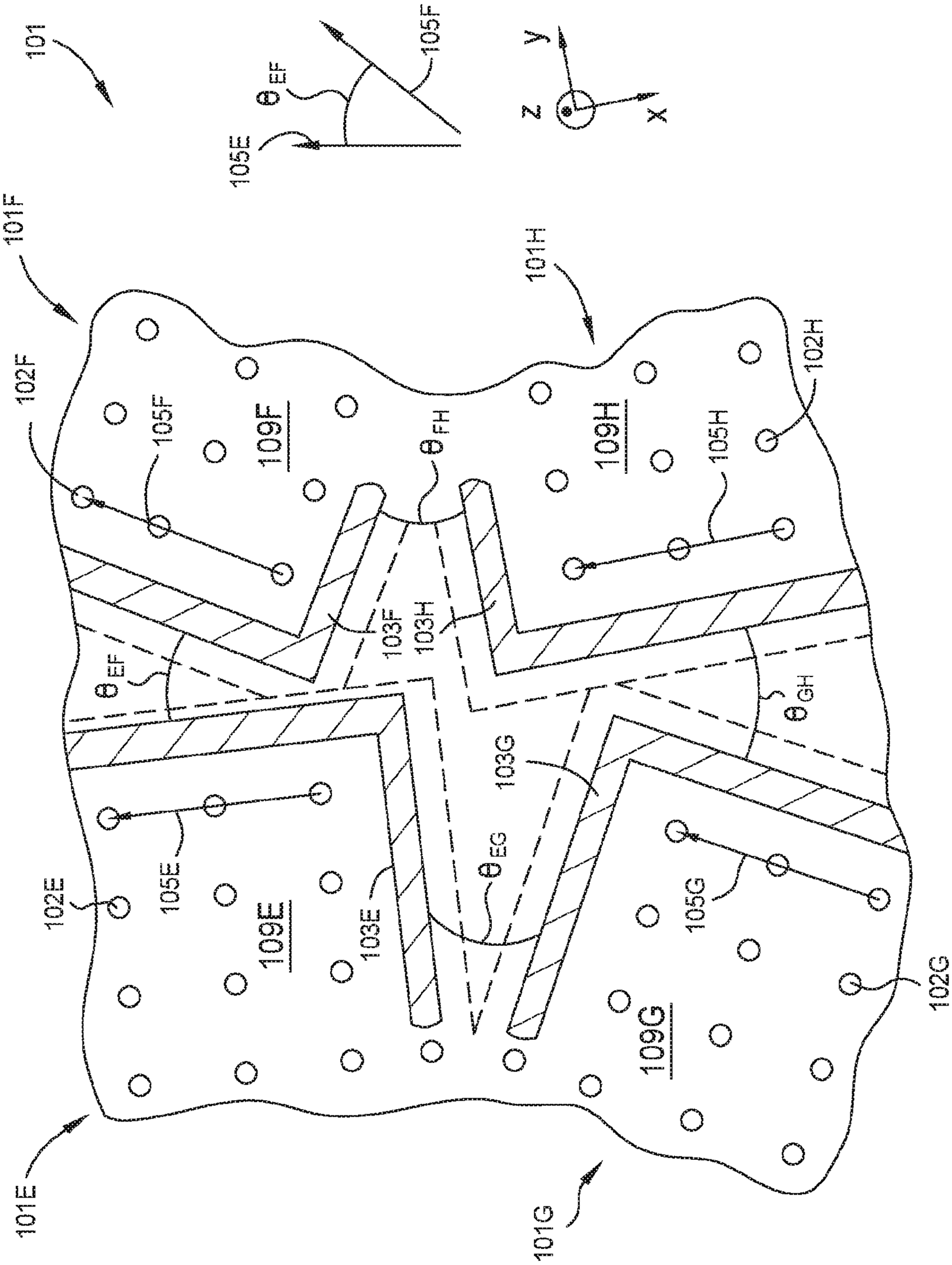

101
105F
θEF
105E
y
z
x
101F
102F
105F
109F
θFH
109H
105H
102H
103F
103H
θEF
θGH
103G
θEG
102E
105E
109E
103E
105G
102G
109G
101E
101G

FIG. 1D

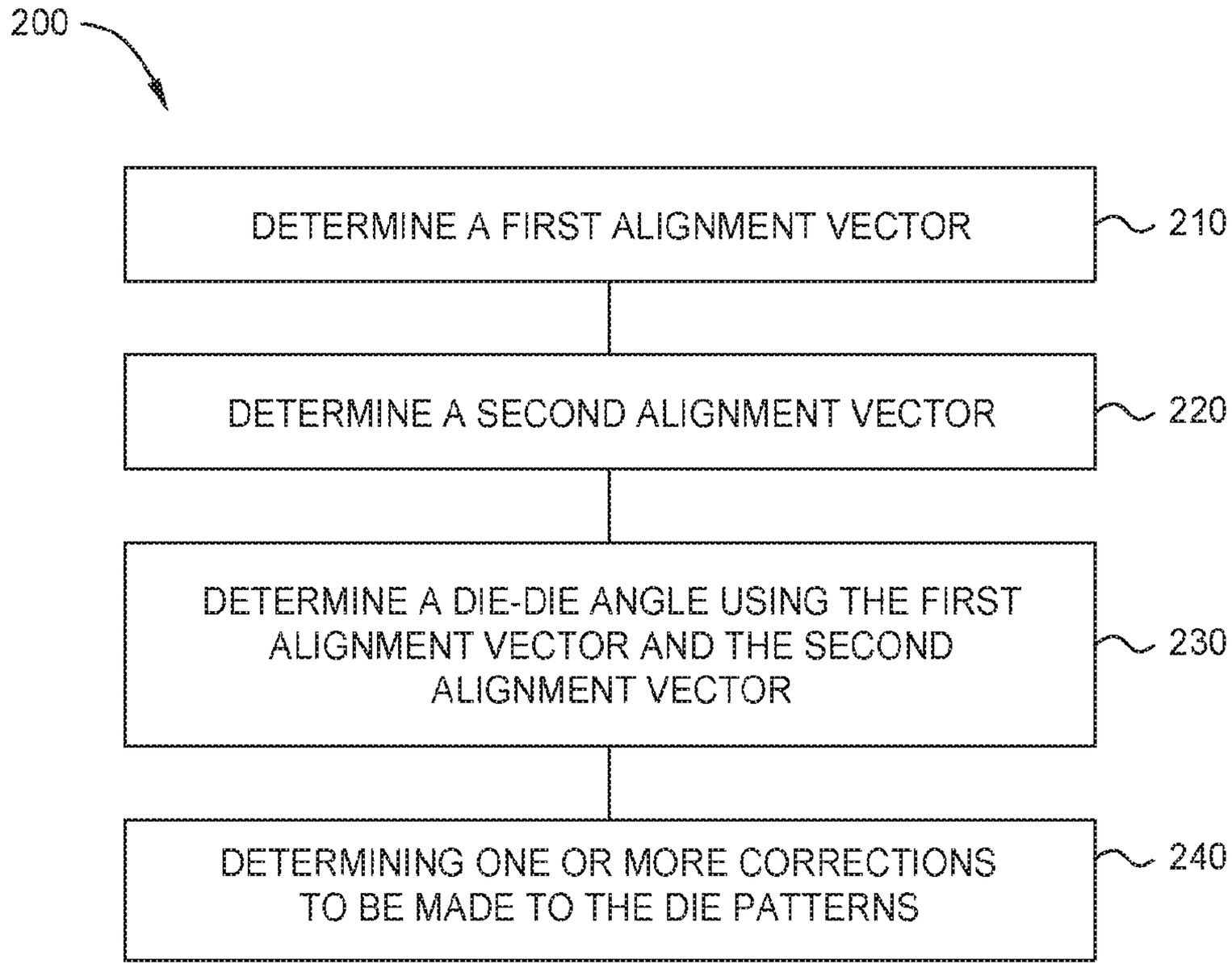

200
DETERMINE A FIRST ALIGNMENT VECTOR
210
DETERMINE A SECOND ALIGNMENT VECTOR
220
DETERMINE A DIE-DIE ANGLE USING THE FIRST ALIGNMENT VECTOR AND THE SECOND ALIGNMENT VECTOR
230
DETERMINING ONE OR MORE CORRECTIONS TO BE MADE TO THE DIE PATTERNS
240

FIG. 2

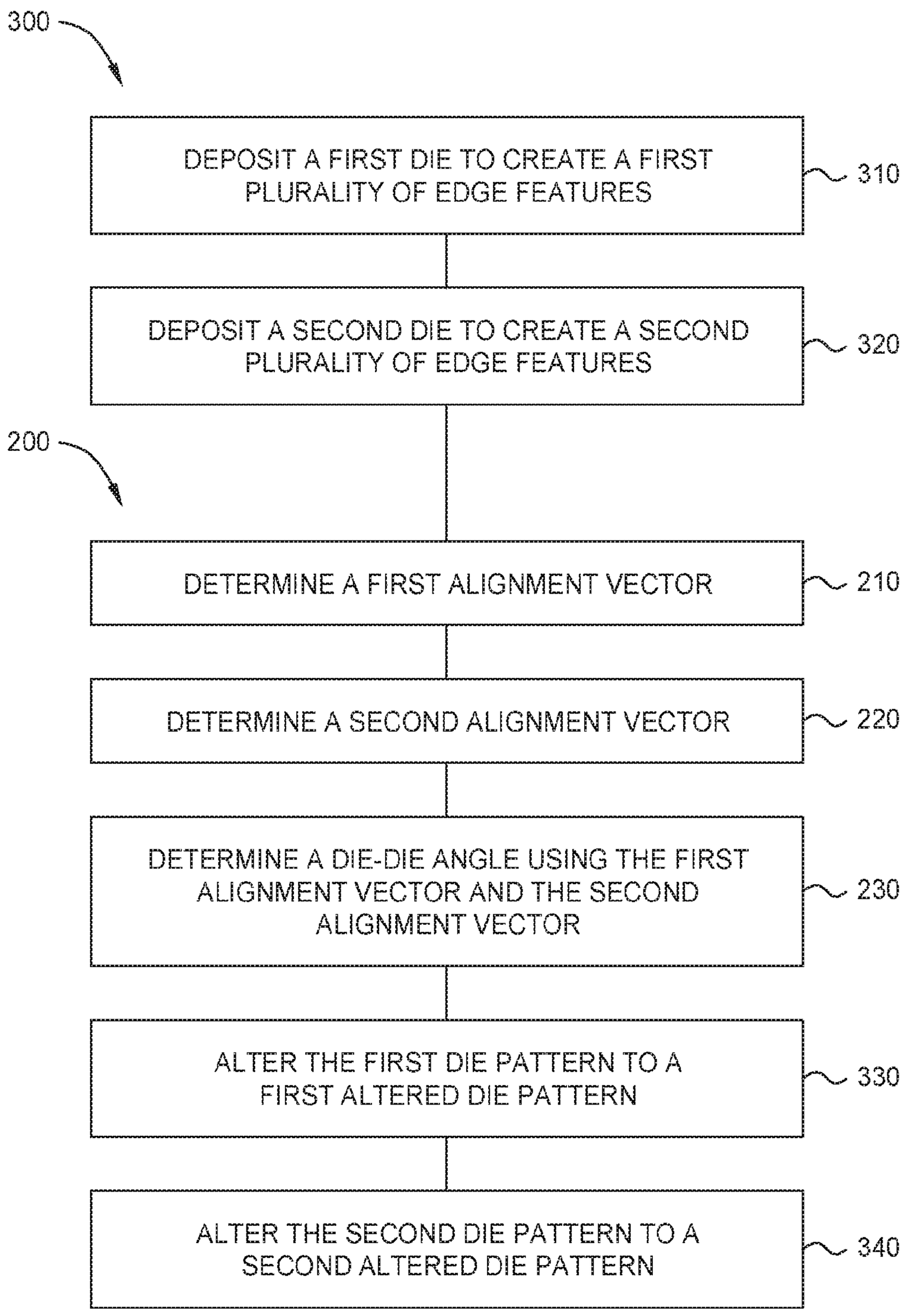

300
DEPOSIT A FIRST DIE TO CREATE A FIRST PLURALITY OF EDGE FEATURES
310
DEPOSIT A SECOND DIE TO CREATE A SECOND PLURALITY OF EDGE FEATURES
320
200
DETERMINE A FIRST ALIGNMENT VECTOR
210
DETERMINE A SECOND ALIGNMENT VECTOR
220
DETERMINE A DIE-DIE ANGLE USING THE FIRST ALIGNMENT VECTOR AND THE SECOND ALIGNMENT VECTOR
230
ALTER THE FIRST DIE PATTERN TO A FIRST ALTERED DIE PATTERN
330
ALTER THE SECOND DIE PATTERN TO A SECOND ALTERED DIE PATTERN
340

FIG. 3

DIE SYSTEM AND METHOD OF COMPARING ALIGNMENT VECTORS

BACKGROUND

Field

Embodiments of the present disclosure relate to an apparatus and a method and, more specifically, to a die system and a method of comparing alignment vectors.

Description of the Related Art

Virtual reality (VR) is generally considered to be a computer generated simulated environment in which a user has an apparent physical presence. A VR experience can be generated in 3D and viewed with a head-mounted display (HMD), such as glasses or other wearable display devices that have near-eye display panels as lenses to display a VR environment that replaces an actual environment.

Augmented reality (AR), however, enables an experience in which a user can still see through the display lenses of the glasses or other HMD device to view the surrounding environment, yet also see images of virtual objects that are generated for display and appear as part of the environment. AR can include any type of input, such as audio and haptic inputs, as well as virtual images, graphics, and video that enhances or augments the environment that the user experiences. In order to achieve an AR experience, a virtual image is overlaid on an ambient environment, with the overlaying performed by optical devices. VR and AR devices can be made by using lithography to deposit features onto a substrate to create a die. However, due the large size of the VR and AR devices in comparison to typical semiconductor lithography patterns, multiple dies and patterns must be stitched together accurately in order to create a functioning device.

One drawback in the art is that current stitching methods do not combine lithography patterns with enough accuracy to ensure a functioning device. In addition, once lithography patterns are deposited, determining how to fix the patterns in the next run of lithography is complicated. Also, there is no simple way to compare the expected feature critical dimensions (CDs) with the actually deposited feature CDs.

Therefore, what is needed in the art is accurate stitching together of dies for AR/VR devices.

SUMMARY

Embodiments herein include a die system and a method of comparing alignment vectors. Alignment vectors are determined from edge features and edge feature patterns of the die. A method of comparing dies and die patterns includes comparing die vectors and/or pattern vectors. The comparison between alignment vectors allows for fixing the die patterns for the next round of processing. The alignment vectors and methods allow for accurate stitching of dies.

In one embodiment, a die system is provided, including a plurality of dies. Each of the dies include a plurality of device features and one or more edge regions. Each edge region includes one or more edge boundary features and a plurality of edge features.

In another embodiment, a method of comparing alignment vectors is provided, including determining a first alignment vector v_1 for a first die, determining a second alignment vector v_2 for a second die, determining a die-die angle θ_{12} using the first alignment vector v_1 and the second alignment vector v_2, altering the first die pattern to a first altered die pattern based on the die-die angle θ_{12}; and altering the second die pattern to a second altered die pattern based on the die-die angle θ_{12}.

In yet another embodiment, a method for determining die alignment is provided, including creating a first plurality of edge features on a first die using a first die pattern, creating a second plurality of edge features on a second die using a second die pattern, determining a first alignment vector v_1 for the first die, determining a second alignment vector v_2 for the second die, determining a die-die angle θ_{12} using the first alignment vector v_1 and the second alignment vector v_2, altering the first die pattern to a first altered die pattern, and altering the second die pattern to a second altered die pattern.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only exemplary embodiments and are therefore not to be considered limiting of its scope, and may admit to other equally effective embodiments.

FIG. **1**A illustrates a die system, according to one embodiment.

FIG. **1**B illustrates a zoomed in portion of die patterns, according to one embodiment.

FIG. **1**C illustrates a zoomed in portion of dies, according to one embodiment.

FIG. **1**D illustrates a zoomed in portion of dies, according to one embodiment.

FIG. **2** is a flow diagram of method operations for comparing two alignment vectors, according to one embodiment.

FIG. **3** is a flow diagram of method operations for determining die alignment, according to one embodiment.

To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

DETAILED DESCRIPTION

Embodiments of the present disclosure include a die system and a method of comparing alignment vectors. The die system includes a plurality of dies arranged in a desired pattern. An alignment vector, such as a die vector, can be determined from edge features of the die. The alignment vectors can be compared to other dies or die patterns in the same system. A method of comparing dies and die patterns includes comparing die vectors and/or pattern vectors. The comparison between alignment vectors allows for fixing the die patterns for the next round of processing. The methods provided allow accurate comparisons between as-deposited edge features, such that accurate stitching of dies can be achieved. Comparing a die vector and a pattern vector allows for compensation of the next die pattern due to errors in the first die pattern. The alignment vector provides a simple way to compare alignment and overlay between dies

and die patterns. Embodiments of the disclosure may be useful for, but are not limited to, aligning dies in a die system.

As used herein, the term "about" refers to a +/−10% variation from the nominal value. It is to be understood that such a variation can be included in any value provided herein.

FIG. **1**A illustrates a die system **100**, according to one embodiment. The die system **100** is configured to be a lens for an optical device, such as a VR or AR headset or device. The die system **100** includes any material used for optical devices, such as, but not limited to, glass or plastic.

As shown, the die system **100** includes a plurality of dies **101** and a plurality of die patterns **111**. As illustrated in FIG. **1**A, each of the plurality of dies **101** and/or plurality of die patterns **111** is separated by solid lines. The die pattern **111** is the pattern of material to be grown to create a desired patterned die **101**. Therefore, the die system **100** can include die patterns **111** (i.e., the desired pattern to be created), die **101** (i.e., the die as patterned), or a mixture of both at any given point in time.

Although the plurality of dies **101** and plurality of die patterns **111** are illustrated in a grid pattern, it is contemplated that the plurality of dies **101** and plurality of die patterns **111** can be in any arrangement. Each die **101** and/or die pattern **111** can have the same shape and/or dimensions as any other die and/or die pattern, or some of the dies and/or die patterns can have different shapes and/or dimensions from the other dies and/or die patterns. The number of dies **101** and/or die patterns **111**, the arrangement of dies and/or die patterns, and the shapes and dimensions of the dies and/or die patterns are chosen by one skilled in the art in order to create the preferred optical device.

FIG. **1**B illustrates a zoomed in portion of die patterns **111**, according to one embodiment. The die patterns **111** can be any mask used in the art, such as a lithography mask, digital mask, or virtual mask. The zoomed in portion of FIG. **1**B illustrates an exemplary intersection between die patterns **111**A, **111**B, **111**C, **111**D. FIG. **1**B illustrates the die patterns **111** to be created in the corresponding dies **101** (illustrated in FIG. **1**C). For example, the die patterns **111**A, **111**B, **111**C, **111**D are used to create the dies **101**A, **101**B, **101**C, **101**D of FIG. **1**C.

Although the die patterns **111**A, **111**B, **111**C, **111**D illustrated in FIG. **1**B are similar, it is to be understood that the die patterns **111**A, **111**B, **111**C, **111**D can be the same or different from one another, and thus the dies **101**A, **101**B, **101**C, **101**D deposited as described in FIG. **1**C below can be the same or different for each die. Although not illustrated in FIGS. **1**B-**1**C, which illustrate the corners of die patterns **111** and dies, it is to be understood that the die patterns extend through the entirety of the die pattern.

As shown, each die pattern **111** includes an edge pattern region **119** (e.g., die patterns **111**A, **111**B, **111**C, **111**D include edge patterns **119**A, **119**B, **119**C, **119**D respectively). The edge pattern region **119** is about 1 μm to about 10 μm wide. The size of the edge pattern region **119** is small enough that the functioning of the eventual die **101** is unaffected. As shown, the edge pattern regions **119**, such as **119**A, **119**B, **119**C, **119**D, include a plurality of edge feature patterns **112**, such as **112**A, **112**B, **112**C, **112**D, and one or more edge boundary feature patterns **113**, such as **113**A, **113**B, **113**C, **113**D. Each of the plurality of edge feature patterns **112** are separated from one another by distances a, b in the x-direction, y-direction respectively. The a, b distances can be the same, or different in a given die pattern **111**, or between die patterns, e.g., **111**A and **111**B. The a, b distances can vary throughout a given die pattern **111**. The distances a, b can be from about 1 nm to about 5 μm. Although shown as a rectangular grid, it is to be understood that the edge feature patterns **112** can have any arrangement.

The edge boundary feature patterns **113** can have a first portion **113'** with a length L' and a second portion **113"** with a second length L". The lengths L', L" can be from about 100 nm to about 10 μm. The lengths L', L" for a given edge boundary feature pattern **113** can be the same or different from other edge boundary feature patterns, e.g., length L' of a first portion **113**A' of an edge boundary feature pattern **113**A is different from length L' of a first portion **113**B' of an edge boundary feature pattern **113**B. Although the edge boundary feature patterns **113** are shown having an L-shape, any shape is contemplated, such as a cross-shape. The distance d between adjacent first portions **113'**, e.g., the distance between **113**A' and **113**C', and the distance d between **113**B' and **113**D', can be the same or different. Likewise, the distance d between adjacent second portions **113"**, e.g., the distance d between **113**A" and **113**B", and the distance d between **113**C" and **113**D", can be the same or different. The distances d can be from about 50 nm to about 5 μm.

For each die pattern **111**, a pattern vector **115** is defined by a direction and a distance between two or more features in the pattern. For example, a pattern vector **115**A is defined by the distance between two edge feature patterns **112**A. In another example, a pattern vector **115**A is defined between an edge feature pattern **112**A and a boundary feature pattern **113**A (not shown). In yet another example, a pattern vector **115**A is defined between an edge feature pattern **112**A and a first portion **113**A' of a boundary feature pattern **113**A (not shown). In each case, each die pattern **111** (e.g., die pattern **111**A) has a corresponding pattern vector **115** (e.g., **115**A). In order to compare pattern vectors **115** between corresponding die patterns **111** (e.g., comparing pattern vector **115**A for die pattern **111**A to pattern vector **115**B for die pattern **111**B), the definition of the pattern vectors **115** between corresponding die patterns is consistent. FIG. **1**B illustrates four die patterns **111**A, **111**B, **111**C, **111**D with their corresponding pattern vectors **115**A, **115**B, **115**C, **115**D.

For a virtual or digital mask, the pattern vector **115** can be determined digitally, e.g., measuring distances and angles by the pixels of the mask. For a physical mask, the pattern vector **115** can be determined using any desired imaging technique, such as scanning electron microscope (SEM). Other possible imaging techniques includes optical inspection and bright field inspection using any wavelength of light.

The pattern vectors **115** between adjacent die patterns **111** are used to compare the correct orientation and placement of the die patterns with respect to one another. For example, the pattern vector **115**A of die pattern **111**A can be compared to the pattern vector **115**B of die pattern **111**B. In FIG. **1**B, the illustrated pattern vectors **115**A, **115**B are oriented correctly with respect to one another, and thus the die patterns **111**A, **111**B are correctly aligned.

FIG. **1**C illustrates a zoomed in portion of dies **101**, according to one embodiment. The zoomed in portion of FIG. **1**C illustrates an exemplary intersection between dies **101**A, **101**B, **101**C, **101**D. The dies **101**A, **101**B, **101**C, **101**D are the patterns deposited from the corresponding die patterns **111**A, **111**B, **111**C, **111**D illustrated in FIG. **1**B. Although the dies **101**A, **101**B, **101**C, **101**D illustrated in FIG. **1**C are similar, it is to be understood that the dies **101**A, **101**B, **101**C, **101**D can be the same or different from one another. Each of the dies **101** are configured to reflect and/or

transmit certain wavelengths of light, depending on the intended function of the optical device.

As shown, each die **101** includes an edge region **109** (e.g., dies **101**A, **101**B, **101**C, **101**D include edge regions **109**A, **109**B, **109**C, **109**D respectively). Each of the edge regions **109** (e.g., **109**A, **109**B, **109**C, **109**D) include patterned material that corresponds to equivalent edge pattern regions **119** (e.g., **119**A, **119**B, **119**C, **119**D) of the die patterns **111** (e.g., **111**A, **111**B, **111**C, **111**D). The edge region **109** is about 1 μm to about 10 μm wide. The size of the edge region **109** is small enough that the functioning of the die **101** is unaffected. As shown, the edge regions **109**, such as **109**A, **109**B, **109**C, **109**D, include a plurality of edge features **102**, such as **102**A, **102**B, **102**C, **102**D, and one or more edge boundary features **103**, such as **103**A, **103**B, **103**C, **103**D. Each of the plurality of edge features **102** (e.g., **102**A, **102**B, **102**C, **102**D) include patterned material that corresponds to the equivalent edge feature patterns **112** (e.g., **112**A, **112**B, **112**C, **112**D). Each of the plurality of edge boundary features **103** (e.g., **103**A, **103**B, **103**C, **103**D) include patterned material that corresponds to the equivalent edge boundary feature patterns **113** (e.g., **113**A, **113**B, **113**C, **113**D). The plurality of edge features **102** are separated from one another by distances a, b in the x-direction, y-direction respectively. The a, b distances can be the same, or different in a given die **101**, or between dies patterns, e.g., **101**A and **101**B. The a, b distances can vary throughout a given die **101**. The distances a, b can be from about 50 nm to about 5000 μm. Although shown as a rectangular grid, it is to be understood that the edge features **102** can have any arrangement.

The plurality of edge features **102** include any features used in optical devices in the art. The plurality of edge features **102** have CD's (such as height and width) of about 10 nm to about 100 μm, such as about 10 nm to about 100 nm, about 20 nm to about 200 nm, or about 60 nm to about 500 nm. The plurality of edge features **102** include vias or holes, according to one embodiment. The plurality of edge features **102** include space lines, according to one embodiment.

The plurality of edge features **102** include pillars, such as those used in metalens arrays, according to one embodiment. The plurality of edge features **102** have differing shapes depending on the desired spectrum of light to filter. The plurality of edge features **102** can be substantially circular, triangular, square, rectangular, or have an uneven shape. The plurality of edge features **102** can be made from any suitable high refractive index material, such as, but not limited to, silicon, silicon oxide, silicon nitride, titanium oxide, tantalum oxide, zirconium oxide, hafnium oxide, gallium arsenide, gallium nitride, and niobium oxide. The plurality of edge features **102** can also be made from metallic materials such as gold, silver, or copper.

The plurality of edge features **102** have a critical dimension (CD), such as width or radius, which is from about 20 nm to about 500 nm. The plurality of edge features **102** have a height which is from about 10 nm to about 2 μm. The CD, height, shape, material, and feature separation distance of the plurality of edge features **102** are selected to create dies **101** that filter out all but a narrow wavelength band of light, according to some embodiments.

In one embodiment, the plurality of edge features **102** are circular or elliptical shaped columns, the columns containing silicon dioxide (SiO_2), silicon (Si), titanium dioxide (TiO_2), gallium nitride (GaN) material, the columns having a radius of about 30 nm to 500 nm, the columns having a height of about 10 nm to 2 um, and the columns having a separation of about 30 nm to about 5000 nm.

The edge boundary features **103** can have a first section **103'** with a length L' and a second section **103"** with a second length L". The lengths L', L" can be from about 100 nm to about 10 μm. The lengths L', L" for a given edge region **109** can be the same or different from other edge regions, e.g., length L' of a first section **103**A' of an edge boundary feature **103**A is different from length L' of a first section **103**B' of an edge boundary feature **103**B. Although the edge boundary features **103** are shown having an L-shape, any shape is contemplated, such as a cross-shape.

The one or more edge boundary features **103** can include the same material that is included in the plurality of edge features **102**. The distance d between adjacent first sections **103'**, e.g., the distance between **103**A' and **103**C', and the distance between **103**B' and **103**D', can be the same or different. Likewise, the d distance between adjacent second sections **103"**, e.g., the distance between **103**A" and **103**B", and the distance between **103**C" and **103**D", can be the same or different. The distances d can be from about 1 nm to about 5000 μm.

For each die **101**, a die vector **105** is defined by a direction and a distance between two features in the die. For example, a die vector **105**A is defined by the distance between two edge features **102**A. In another example, a die vector **105**A is defined between an edge feature **102**A and an edge boundary feature **103**A (not shown). In yet another example, a die vector **105**A is defined between an edge feature **102**A and a first portion **103**A' of a boundary feature **103**A (not shown). In each case, each die **101** (e.g., die **101**A) has a corresponding die vector **105** (e.g., **105**A). The die vector **105** can be determined using an image of the die **101**, and the die vector is determined by measuring distances between pixels of the image of the die. Any desired imaging technique can be used to make an image of the die, such as SEM.

Other possible imaging techniques includes optical inspection and bright field inspection using any wavelength of light. The desired wavelength of light can be chosen by one skilled in the art to match the CD's of the edge features **102** and the edge boundary features **103**. The error of the die vector **105** is about the size of one pixel. FIG. **1**C illustrates four dies **101**A, **101**B, **101**C, **101**D with their corresponding die vectors **105**A, **105**B, **105**C, **105**D.

The die vectors **105** between adjacent dies **101** are used to compare the correct orientation and placement of the die patterns with respect to one another. For example, the die vector **105**A of die **101**A can be compared to the die vector **105**B of die **101**B. In FIG. **1**C, the illustrated die vectors **105**A, **105**B are oriented correctly with respect to one another, and thus the dies **101**A, **101**B are correctly aligned.

During creation of the die **101** using the die pattern **111**, the dimensions of the plurality of edge features **102** can differ from the plurality of edge feature patterns **112** of the die pattern **111**. For example, process drift can result in a shift of location of an edge feature **102** from an edge feature pattern **112**, the thickness of the edge feature can vary from the edge feature pattern, the underlying substrate of the die can be non-uniform, there can be noise in the image taken of the die, or there could be an error in the pattern recognition algorithm used to make the image of the die. In these cases, the die vector **105** (e.g., the die vector **105**A illustrated in FIG. **1**C) can vary from the pattern vector **115** (e.g., the pattern vector **115**A illustrated in FIG. **1**B). Thus, comparison of the die vector **105** and the pattern vector **115** is used to refine the die pattern **111** for the next die **101**. The angle $\theta_{AA'}$ defined between the die vector **105**A and the pattern vector **115**A is calculated using the formula

$$\cos(\theta_{AA'})=(v_A \cdot v_{A'})/(|v_A||v_{A'}|),$$

where $|v_A|$ is the absolute value of the die vector, and $|v_{A'}|$ is the absolute value of the pattern vector, according to one embodiment. For small angles, the formula simplifies to

$$\theta_{AA'}=(v_A \cdot v_{A'})/(|v_A||v_{A'}|),$$

as $\cos(\theta_{AA'})\approx\theta_{AA'}$ for small $\theta_{AA'}$. The x-component of the die vector **105**A is compared to the x-component of the pattern vector **115**A, and the y-component of the die vector **105**A is compared to the y-component of the pattern vector **115**A, according to one embodiment. The error of angle $\theta_{AA'}$ is less than about 150 arcsec, according to one embodiment. The x-component difference, the y-component difference, and the angle $\theta_{AA'}$ can be used to correct the die pattern **111**A, which results in a more accurate deposition of die **101**A.

FIG. **1**D illustrates a zoomed in portion of dies **101**, according to one embodiment. The zoomed in portion of FIG. **1**D illustrates an intersection of four dies **101**E, **101**F, **101**G, **101**H include edge regions **109**E, **109**F, **109**G, **109**H respectively. In comparison with FIG. **1**C, which illustrates an intersection of four dies **101**A, **101**B, **101**C, **101**D which are properly aligned, FIG. **1**D illustrates an intersection of four dies **101**E, **101**F, **101**G, **101**H that are improperly aligned. For example, the dies **101**E, **101**F, **101**G, **101**H are illustrated as not being at approximately 90° to one another, so that the corners of each of the dies do not meet at an approximately 90° angle.

For each die **101**, a die vector **105** is defined by a direction and a distance between two features in the die. For example, a die vector **105**E is defined by the distance between two edge features **102**E. In another example, a die vector **105**E is defined between an edge feature **102**E and a boundary feature **103**E (not shown). In yet another example, a die vector **105**E is defined between an edge feature **102**E and a first portion **103**E' of a boundary feature **103**E (not shown). In each case, each die **101** (e.g., die **101**E) has a corresponding die vector **105** (e.g., **105**E). FIG. **1**D illustrates four dies **101**E, **101**F, **101**G, **101**H with their corresponding die vectors **105**E, **105**F, **105**G, **105**H.

The die vectors **105** between adjacent die patterns **111** are used to compare the correct orientation and placement of the die patterns with respect to one another. For example, the die vector **105**E of die **101**E can be compared to the die vector **105**F of die **101**F. In FIG. **1**D, the illustrated die vectors **105**E, **105**F are not oriented correctly with respect to one another, and thus the dies **101**E, **101**F are not correctly aligned.

Thus, comparison of a die vector **105**E of a die **101**E and a die vector **105**F of a die **101**F is used to refine corresponding die patterns **111**E, **111**F for the next die **101**E, **101**F deposition. The angle θ_{EF} defined between the die vector **105**E and the die vector **105**F is calculated using the formula

$$\cos(\theta_{EF})=(v_E \cdot v_F)/(|v_E||v_F|),$$

where $|v_E|$ is the absolute value of the die vector **105**E, and $|v_F|$ is the absolute value of the die vector **105**F, according to one embodiment. For small angles, the formula simplifies to

$$\theta_{EF}=(v_E - v_F)/(|v_E||v_F|),$$

as $\cos(\theta_{EF})\approx\theta_{EF}$ for small θ_{EF}. The x-component of the die vector **105**E is compared to the x-component of the die vector **105**F, and the y-component of the die vector **105**E is compared to the y-component of the die vector **105**F, according to one embodiment. The x-component difference, the y-component difference, and the angle θ_{EF} can be used to correct the die patterns, which results in a more accurate deposition of dies **101**E, **101**F. The error of angle θ_{EF} is less than about 150 arcsec, according to one embodiment. For example, in the dies **101** illustrated in FIG. **1**D, the angle θ_{EF} is approximately the same as the angle misalignment between adjacent dies **101**E, **101**F.

As described above, alignment vectors can be used to compare features of dies **101** and/or die patterns **111** to one another. The alignment vectors can include any combination of die vectors **105** (illustrated in FIGS. **1**C-**1**D) and pattern vectors **115** (illustrated in FIG. **1**B). Possible combinations of comparisons between alignment vectors include, but are not limited to, comparisons between die vectors **105** of adjacent dies **101** (e.g., comparison of die vectors **105**A and **105**B), comparisons between pattern vectors **115** of adjacent die patterns **111** (e.g., comparison of pattern vectors **115**A and **115**B), and comparisons between die vectors **105** and pattern vectors **115** (e.g., comparison of die vector **105**A and pattern vector **115**A). Although comparisons between two alignment vectors is described above and below, it is to be understood that comparison of any number of alignment vectors could be conducted.

In addition, although the dies **101** of die system **100** are shown to be in the same x-y plane in a single layer (e.g., dies **101**A, **101**B, **101**C, **101**D illustrated in FIG. **1**C; dies **101**E, **101**F, **101**G, **101**H illustrated in FIG. **1**D), the alignment vectors can be determined for dies in different layers, and comparison between alignment vectors in different layers can be performed as described in FIGS. **2** and **3** below.

FIG. **2** is a flow diagram of method **200** operations for comparing alignment vectors, according to one embodiment. Although the method **200** operations are described in conjunction with FIG. **2**, persons skilled in the art will understand that any system configured to perform the method operations, in any order, falls within the scope of the embodiments described herein.

The method **200** begins at operation **210**, where a first alignment vector v_1 is determined. The first alignment vector can be either a die vector **105** or a pattern vector **115** as described above. The first alignment vector v_1 can be determined using any suitable lithography tool or metrology tool in the art.

According to some embodiments, the first alignment vector v_1 is a die vector **105**A. The first alignment vector v_1 is defined by a first x component and a first y component. The first x component is equal to the x distance between two of a plurality of edge features **102**A of a first die **101**A, and the first y component is equal to the y distance between two of the plurality of edge features of the first die. According to some embodiments, the first alignment vector v_1 is a pattern vector **115**. The first alignment vector v_1 is defined by a first x component and a second y component. The first x component is equal to the x distance between two of a plurality of edge feature patterns **112**A of a first die pattern **111**A, and the first y component is equal to the y distance between the same two of the plurality of edge feature patterns of the first die pattern.

At operation **220**, a second alignment vector v_2 is determined. The second alignment vector v_2 can be determined using any suitable lithography tool or metrology tool in the art.

According to some embodiments, the second alignment vector v_2 is a die vector **105**B. The second alignment vector v_2 is defined by a second x component and a second y component. The second x component is equal to the x

distance between two of a plurality of edge features of a second die **101**B, and the second y component is equal to the y distance between two of the plurality of edge features of the second die.

According to some embodiments, the second alignment vector v_2 is a pattern vector **115**B. The second alignment vector v_2 is defined by a second x component and a second y component. The second x component is equal to the x distance between two of a plurality of edge feature patterns **112**B of a second die pattern **111**B, and the first y component is equal to the y distance between two of the plurality of edge feature patterns of the second die pattern. At operation **230**, a die-die angle θ_{12} is determined using the first alignment vector v_1 and the second alignment vector v_2.

The angle θ_{12} is calculated using the formula

$$\cos(\theta_{12})=(v_1 \cdot v_2)/(|v_1||v_2|),$$

where $|v_1|$ is the absolute value of the first alignment vector v_1, and $|v_2|$ is the absolute value of the second alignment vector v_2, according to one embodiment. For small angles, the formula simplifies to

$$\theta_{12}=(v_1 \cdot v_2)/(v_1||v_2|),$$

as $\cos(\theta_{12}) \approx \theta_{12}$ for small θ_{12}.

At operation **240**, one or more corrections are determined to be made to the first die pattern **111**A and/or the second die pattern **111**B. The determining one or more corrections to the first die pattern **111**A and the second die pattern **111**B include altering the first die pattern to a first altered die pattern based on the angle **612**, and altering the second die pattern to a second altered die pattern based on the angle θ_{12}, according to one embodiment.

The second alignment vector v_2 is analogous with the first alignment vector v_1; that is, the die-die angle θ_{12} between alignment vectors v_1 and v_2 is expected to be small. For example, in the embodiment where the first alignment vector v_1 is a die vector for a die pattern (e.g. die vector **105**A for die **101**A) and the second alignment vector v_2 is a pattern vector for a die pattern (e.g., pattern vector **115**A for die pattern **111**A), a small die-die angle θ_{12} is expected for a deposited die to be similar to the die pattern. However, due to process drift or other factors listed above, a large die-die angle θ_{12} can indicate that the die **101**A and associated die pattern do not match die pattern **111**A, and thus the one or more corrections can be made in future die patterns. For example, pattern features of the die pattern **111**A can be shifted if the features of the corresponding die are out of place.

In another example, in the embodiment where the first alignment vector v_1 is a die vector for a first die pattern (e.g. die vector **105**A for die **101**A) and the second alignment vector v_2 is a die vector for a second die pattern (e.g. die vector **105**B for die **101**B), a small die-die angle θ_{12} is expected for adjacent dies to be similar to one another. However, due to process drift or other factors listed above, a large die-die angle θ_{12} can indicate that adjacent dies a do not match, and thus the one or more corrections can be made in future die patterns. For example, if the two dies are not aligned correctly (e.g., the dies **101**E, **101**F illustrated in FIG. **1**D), the angle of the entire second die pattern with respect to the first die pattern can be adjusted.

FIG. **3** is a flow diagram of method **300** operations for a method for determining die alignment, according to one embodiment. Although the method **300** operations are described in conjunction with FIG. **3**, persons skilled in the art will understand that any system configured to perform the method operations, in any order, falls within the scope of the embodiments described herein.

The method **300** begins at operation **310**, where a first die **101**A is deposited and a first plurality of edge features **102**A is created. The first die **101**A can be created using a first die pattern **111**A, as described above.

At operation **320**, a second die **101**B is deposited and a second plurality of edge features **102**B is created. The second die **101**B can be created using a second die pattern **111**B, as described above.

At operation **210**, a first alignment vector v_1 is determined. The first alignment vector v_1 is a die vector **105**A. The first alignment vector v_1 is defined by a first x component and a first y component. The first x component is equal to the x distance between two of a plurality of edge features **102**A of a first die **101**A, and the first y component is equal to the y distance between the same two of the plurality of edge features of the first die. The first alignment vector v_1 can be determined using any suitable metrology tool in the art.

At operation **220**, a second alignment vector v_2 is determined. The second alignment vector v_2 is a die vector **105**B. The second alignment vector v_2 is defined by a second x component and a second y component. The second x component is equal to the x distance between two of a plurality of edge features of a second die **101**B, and the second y component is equal to the y distance between the same two of the plurality of edge features of the second die. The second alignment vector v_2 can be determined using any suitable metrology tool in the art.

At operation **230**, a die-die angle θ_{12} is determined using the first alignment vector v_1 and the second alignment vector v_2.

The die-die angle θ_{12} is calculated using the formula

$$\cos(\theta_{12})=(v_1 \cdot v_2)/(|v_1||v_2|),$$

where $|v_1|$ is the absolute value of the first alignment vector v_1, and $|v_2|$ is the absolute value of the second alignment vector v_2, according to one embodiment. For small angles, the formula simplifies to

$$\theta_{12}=(v_1 \cdot v_2)/(|v_1||v_2|),$$

as $\cos(\theta_{12}) \approx \theta_{12}$ for small θ_{12}.

At operation **330**, the first alignment vector v_1 and the second alignment vector v_2 are compared to determine a correction to be made to the first die pattern **111**A. In one embodiment, the first die pattern **111**A is used as reference die, and the alignment correction data is saved by a metrology tool and sent to the lithography tool at the same time. The alignment correction data is used to correct the second die alignment during next cycle of exposure in operation **340**. Thus, alignment correction data is used to make a first altered die pattern **111**A'. The first altered die pattern **111**A' incorporates improvements from the comparison of the first alignment vector v_1 and the second alignment vector v_2.

At operation **340**, the first alignment vector v_1 and the second alignment vector v_2 are compared to determine a correction to be made to the second die pattern **111**B. The second die pattern **111**B is altered to a second altered die pattern **111**B'. The second altered die pattern **1111**B' incorporates improvements from the comparison of the first alignment vector v_1 and the second alignment vector v_2. The second altered die pattern **111**B' incorporates some or all of the alignment correction data determined in operation **330**, according to one embodiment.

As described above, a die system and a method of comparing alignment vectors is disclosed herein. The die

system includes a plurality of dies arranged in a desired pattern. An alignment vector, such as a die vector, can be determined from edge features of the die. The alignment vectors can be compared to other dies or die patterns in the same system. A method of comparing dies and die patterns includes comparing die vectors and/or pattern vectors. The comparison between alignment vectors allows for fixing the die patterns for the next round of processing.

The methods provided allow accurate comparisons between as-deposited edge features, such that accurate stitching of dies can be achieved. Comparing a die vector and a pattern vector allows for compensation of the next die pattern due to errors in the first die pattern. The alignment vector provides a simple way to compare alignment and overlay between dies and die patterns.

While the foregoing is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. A lens of an augmented reality or virtual reality device comprising:

a plurality of dies, each die of the lens of the augmented reality or virtual reality device reflects or transmits wavelengths of light comprising:

a central region comprising a plurality of device features; and

one or more edge regions, each edge region comprising:

one or more edge boundary features at least partially surrounding the central region; and

a plurality of edge features disposed adjacent to the edge boundary features, the plurality of edge features include metalens array pillars, each edge feature filters a spectrum of light, each edge is configured to be separated from one another by a pre-determined distance.

2. The lens of claim **1**, wherein the plurality of device features comprises one or more vias.

3. The lens of claim **1**, wherein the plurality of device features comprises one or more line spaces.

4. The die system of lens claim **1**, wherein a spacing between the plurality of device features is different than the spacing between the plurality of edge features.

5. A method of comparing alignment vectors, comprising:

determining a first alignment vector v_1 for a first die and a first die pattern;

determining a second alignment vector v_2 for a second die and a second die pattern;

determining a die-die angle θ_{12} using the first alignment vector v_1 and the second alignment vector v_2;

altering the first die pattern to a first altered die pattern based on the die-die angle θ_{12}; and

altering the second die pattern to a second altered die pattern based on the die-die angle θ_{12}.

6. The method of claim **5**, wherein:

the first alignment vector v_1 is a die vector,

the first alignment vector v_1 is defined by a first x component and a first y component,

the first x component is equal to a x distance between two of a plurality of edge features of the first die,

the first y component is equal to a y distance between two of the plurality of edge features of the first die,

the second alignment vector is a die vector,

the second alignment vector v_2 is defined by a second x component and a second y component,

the second x component is equal to the x distance between two of a plurality of edge features of the second die, and

the second y component is equal to the y distance between two of the plurality of edge features of the second die.

7. The method of claim **6**, wherein the determining the die-die angle θ_{12} comprises solving the equation $\cos(\theta_{12})=(v_1 \cdot v_2)/(|v_1||v_2|)$, where $|v_1|$ is the absolute value of the first alignment vector v_1, and $|v_2|$ is the absolute value of the second alignment vector v_2.

8. The method of claim **5**, wherein:

the first alignment vector is a die vector,

the first alignment vector v_1 is defined by a first x component and a first y component,

the first x component is equal to a x distance between two of a plurality of edge features of the first die,

the first y component is equal to a y distance between two of the plurality of edge features of the first die,

the second alignment vector is a pattern vector,

the second alignment vector v_2 is defined by a second x component and a second y component,

the second x component is equal to the x distance between two of a plurality of edge feature patterns of the second die pattern, and

the second y component is equal to the y distance between two of the plurality of edge feature patterns of the second die pattern.

9. The method of claim **8**, wherein the determining the die-die angle θ_{12} comprises solving the equation $\cos(\theta_{12})=(v_1 \cdot v_2)/(|v_1||v_2|)$, where $|v_1|$ is the absolute value of the first alignment vector v_1, and $|v_2|$ is the absolute value of the second alignment vector v_2.

10. The method of claim **8**, wherein each of the first die and the second die further comprise one or more edge boundary features.

11. The method of claim **8**, wherein the plurality of edge features comprises one or more pillars.

12. The method of claim **8**, wherein the plurality of edge features comprises one or more vias.

13. The method of claim **8**, wherein the plurality of edge features comprises one or more line spaces.

14. A method for determining die alignment, comprising:

creating a first plurality of edge features on a first die using a first die pattern;

creating a second plurality of edge features on a second die using a second die pattern;

determining a first alignment vector v_1 for the first die;

determining a second alignment vector v_2 for the second die;

determining a die-die angle θ_{12} using the first alignment vector v_1 and the second alignment vector v_2;

altering the first die pattern to a first altered die pattern based on the die-die angle θ_{12}; and

altering the second die pattern to a second altered die pattern based on the die-die angle θ_{12}.

15. The method of claim **14**, wherein the method is repeated using the first altered die pattern as the first die pattern and the second altered die pattern as the die second pattern.

16. The method of claim **14**, wherein:

the first alignment vector v_1 is a die vector,

the first alignment vector v_1 is defined by a first x component and a first y component,

the first x component is equal to a x distance between two of the first plurality of edge features of the first die,

the first y component is equal to a y distance between two of the first plurality of edge features of the first die,

the second alignment vector v_2 is a die vector,

the second alignment vector v_2 is defined by a second x component and a second y component,

the second x component is equal to the x distance between two of the second plurality of edge features of the second die, and

the second y component is equal to the y distance between two of the second plurality of edge features of the second die.

17. The method of claim **16**, wherein the determining the die-die angle θ_{12} comprises solving the equation $\cos(\theta_{12})=(v_1 \cdot v_2)/(|v_1||v_2|)$, where $|v_1|$ is the absolute value of the first alignment vector v_1, and $|v_2|$ is the absolute value of the second alignment vector v_2.

18. The method of claim **14**, wherein each of the first die and the second die further comprise one or more edge boundary features.

19. The method of claim **14**, wherein each of the first die and the second die comprises a plurality of device features comprising one or more pillars.

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