US 20020171047A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2002/0171047 A1**

Chan et al. (43) **Pub. Date: Nov. 21, 2002**

(54) INTEGRATED LASER DIODE ARRAY AND APPLICATIONS

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(21) Appl. No.: **09/820,030**

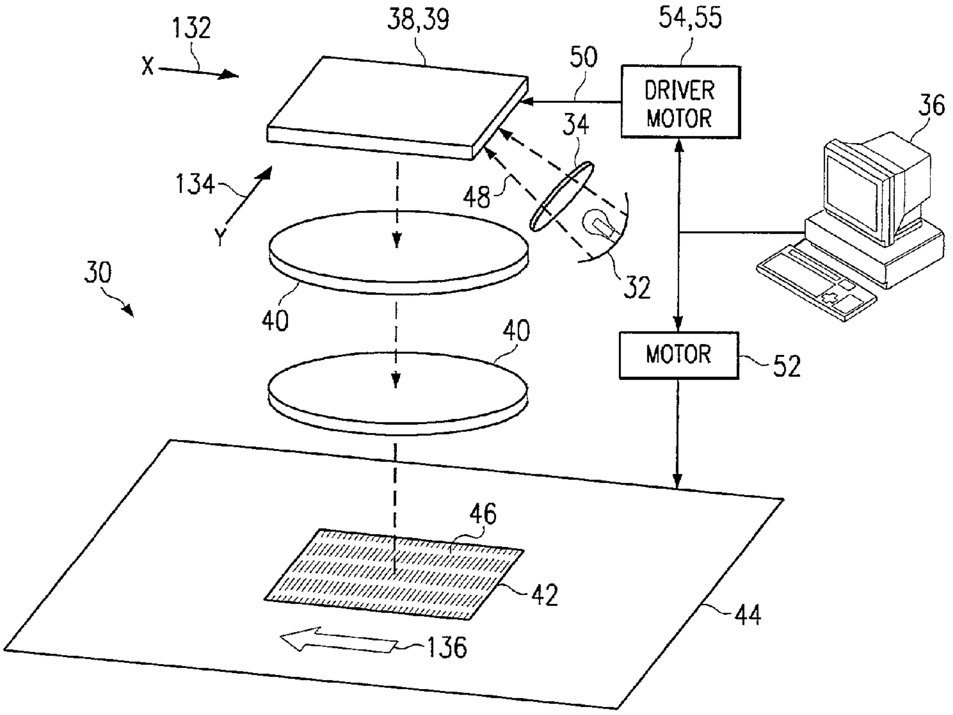
(22) Filed: **Mar. 28, 2001**

Publication Classification

(51) **Int. Cl.^{7}** **G21G 5/00**
(52) **U.S. Cl.** **250/492.1**

(57) ABSTRACT

A system for performing digital lithography onto a subject is provided. The system includes a laser diode or LED array for generating and projecting a digital pattern. The array has a plurality of lasers which may be controlled either individually or as a group to produce the desired pattern. A lens system may then direct the digital pattern to the subject, thereby enabling the lithography.



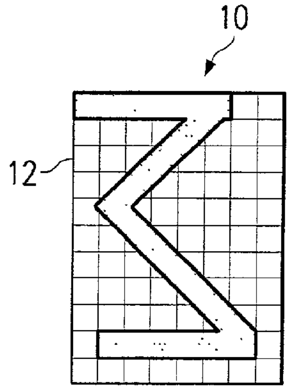


Fig. 1a
(PRIOR ART)

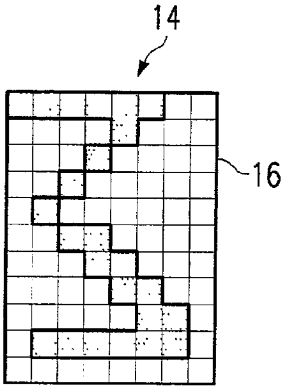


Fig. 1b
(PRIOR ART)

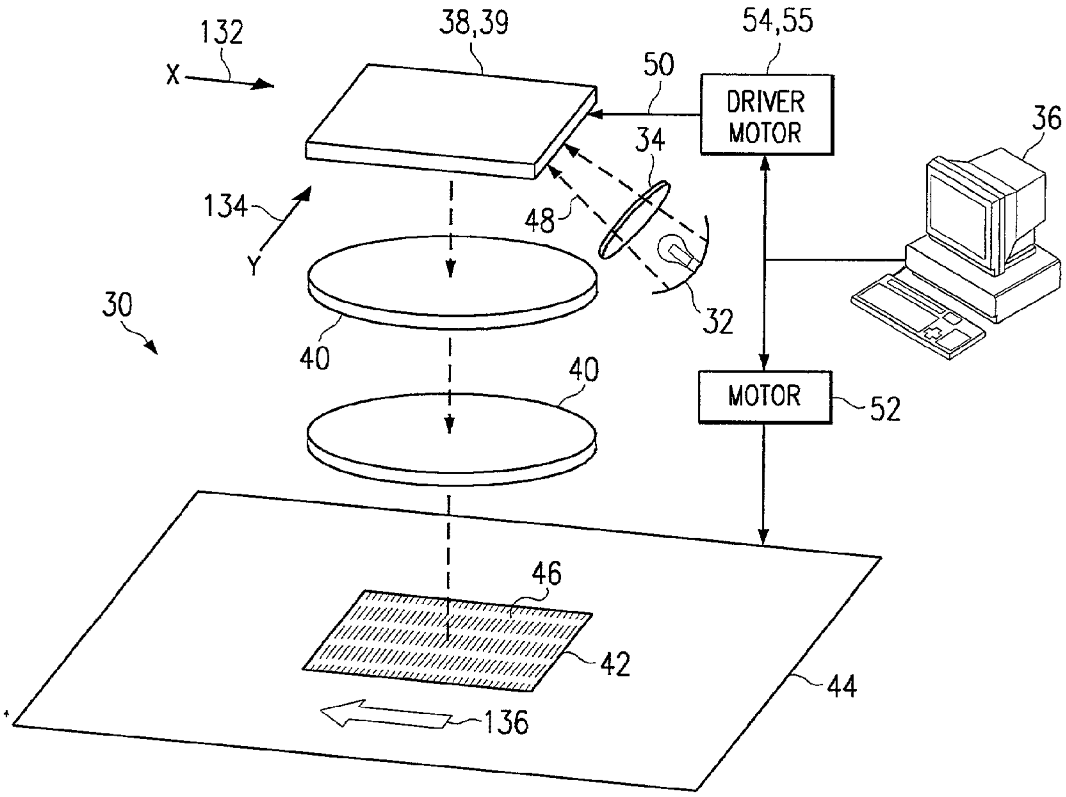


Fig. 2

Fig. 3a

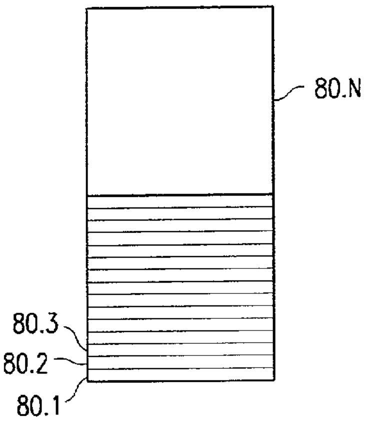
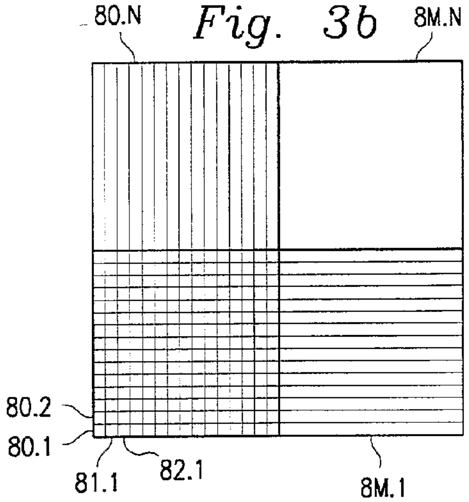


Fig. 3b



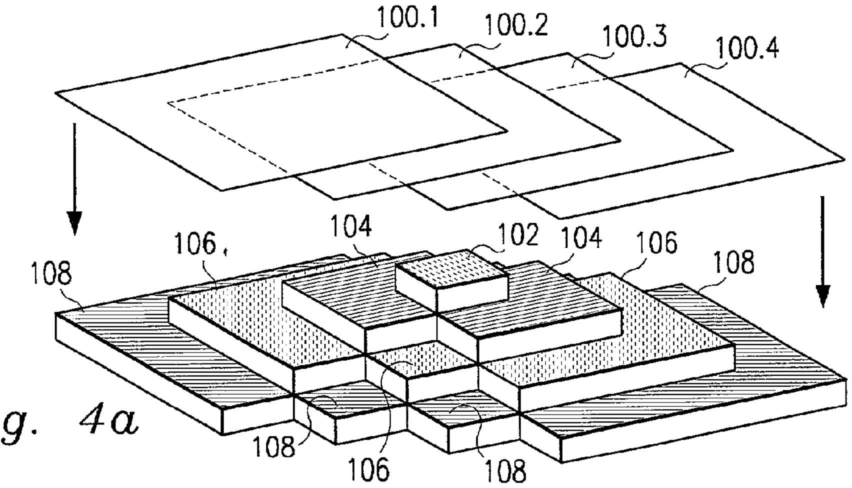


Fig. 4a

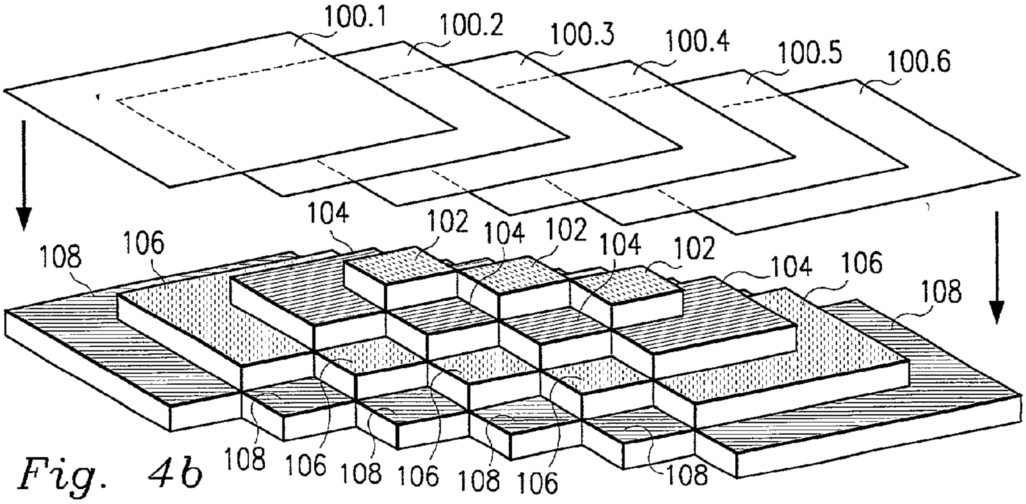


Fig. 4b

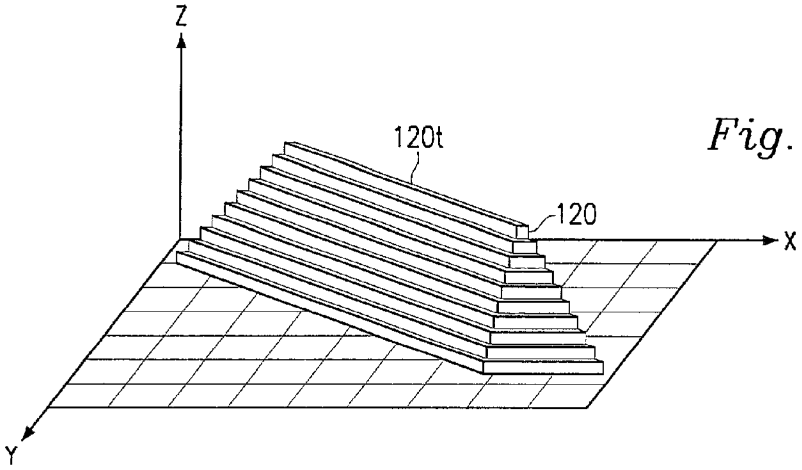


Fig. 5

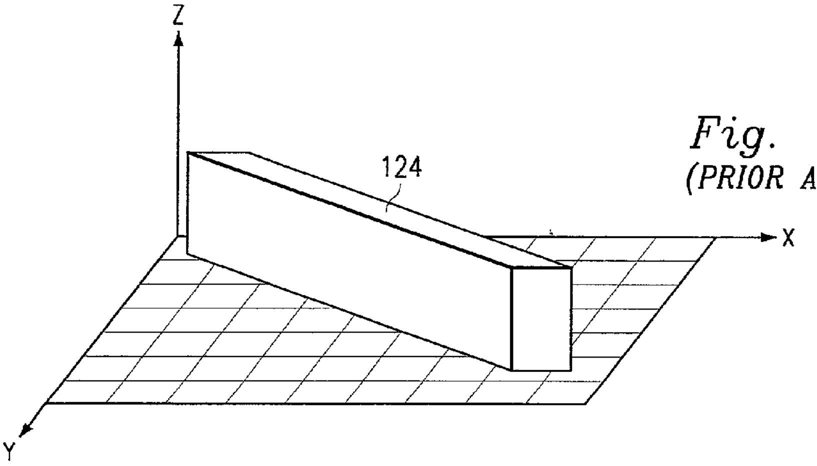


Fig. 6a
(PRIOR ART)

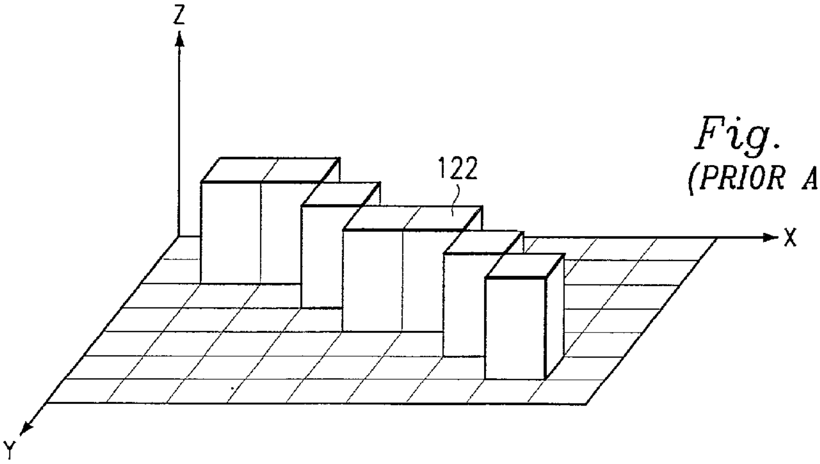
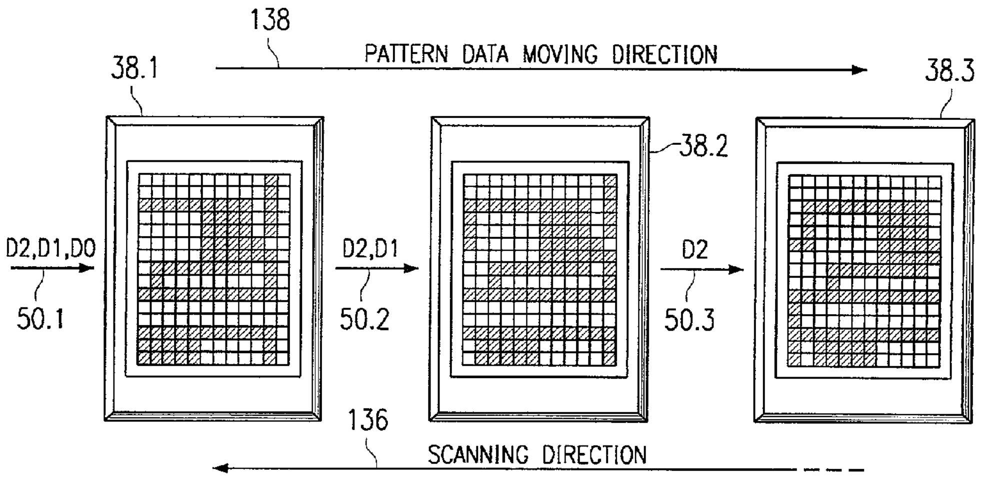


Fig. 6b
(PRIOR ART)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38.1
38.2
38.3
D2,D1,D0
50.1
D2,D1
50.2
D2
50.3
136
SCANNING DIRECTION

Fig. 7

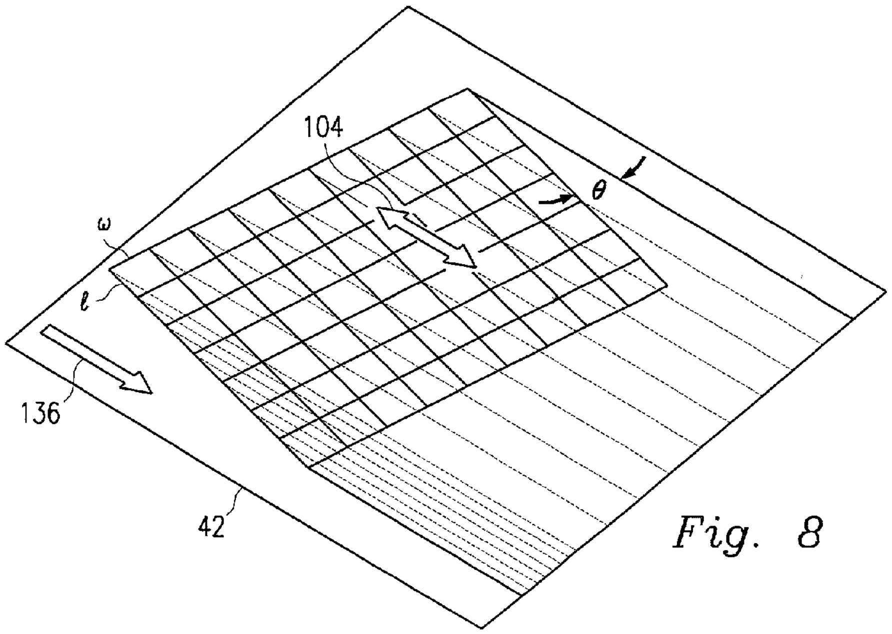
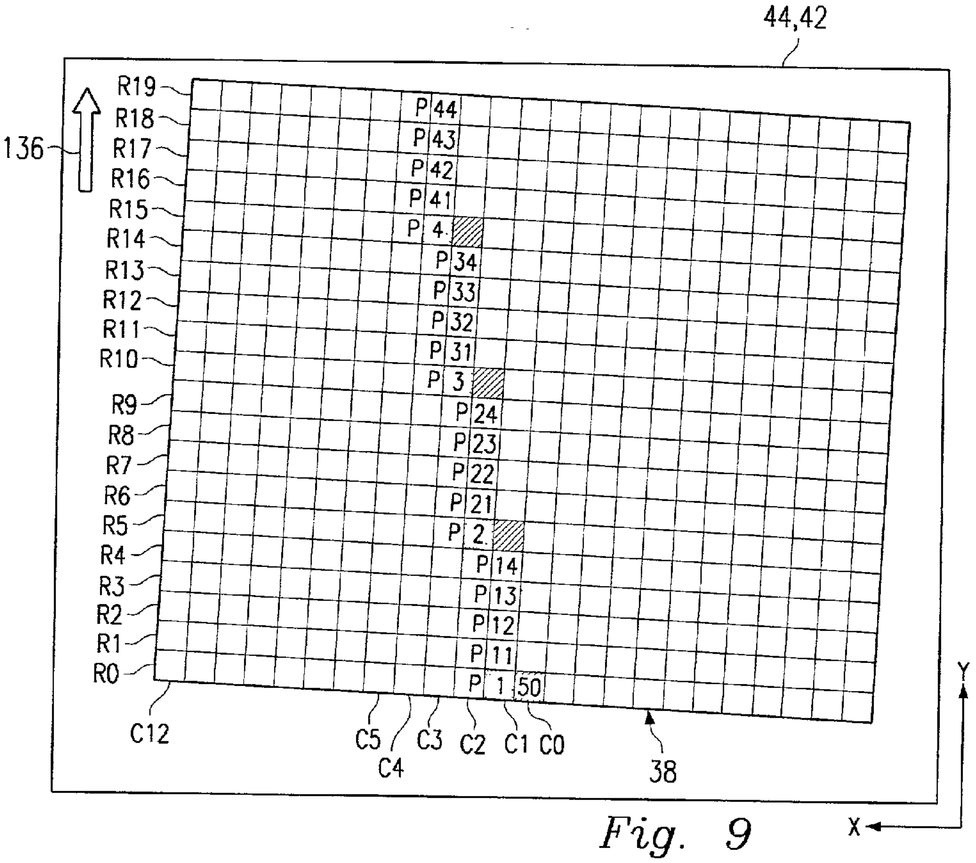

104
θ
ω
ℓ
136
42

Fig. 8


44,42
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R19
R18
R17
R16
R15
R14
R13
R12
R11
R10
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R5
R4
R3
R2
R1
R0
P 44
P 43
P 42
P 41
P 4
P 34
P 33
P 32
P 31
P 3
P 24
P 23
P 22
P 21
P 2
P 14
P 13
P 12
P 11
P 1
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C5
C4
C3
C2
C1
C0
38
Y
X

Fig. 9

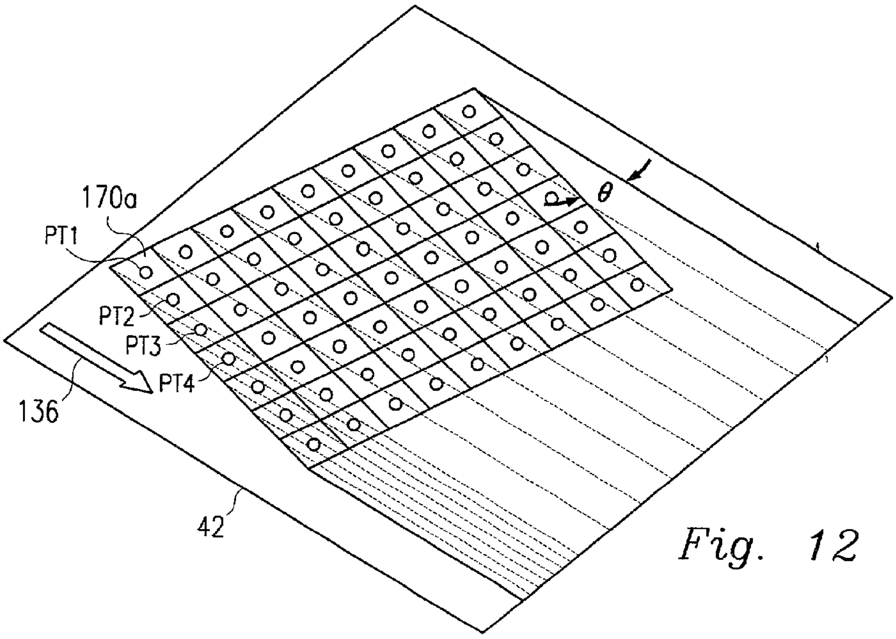

170a
PT1
PT2
PT3
PT4
136
42
θ

Fig. 12

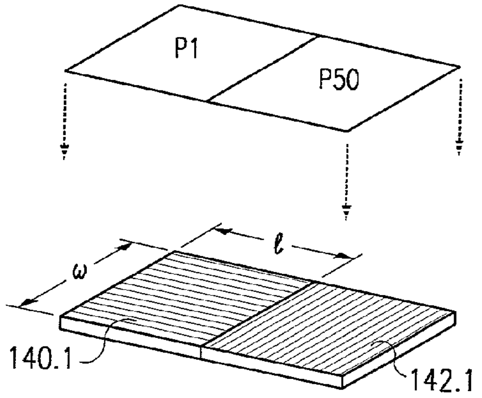


Fig. 10.1

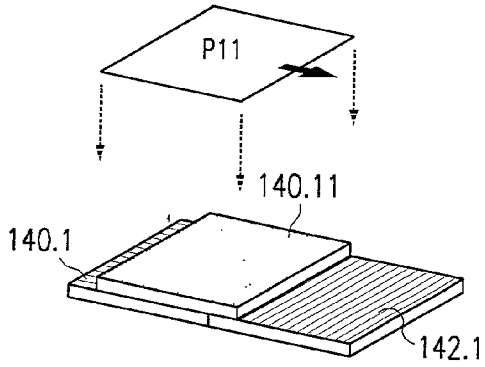


Fig. 10.2

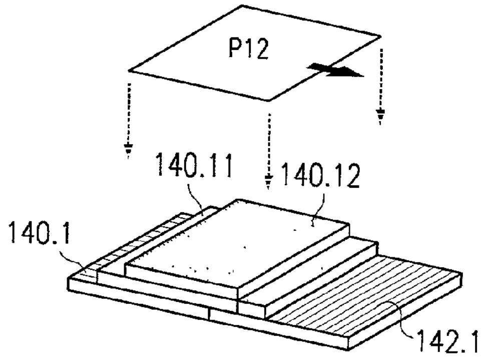
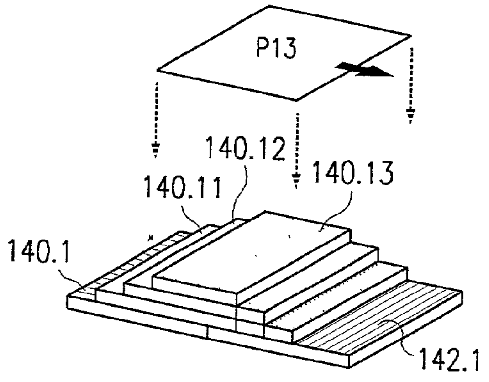


Fig. 10.3



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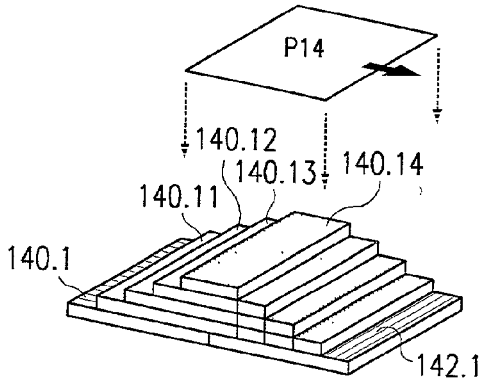
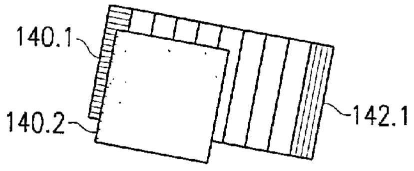


Fig. 10.5



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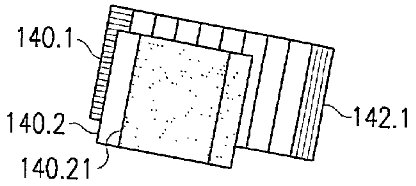

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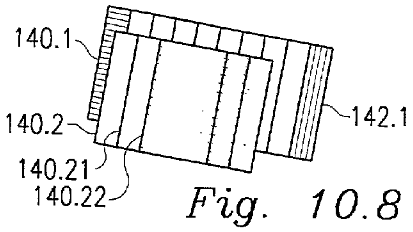

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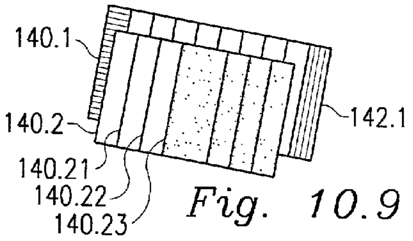

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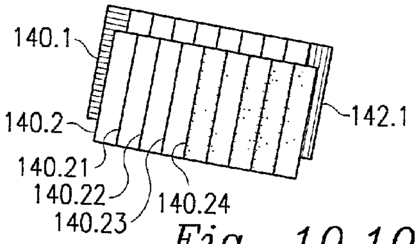

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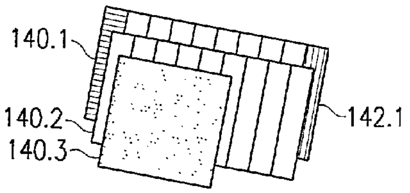
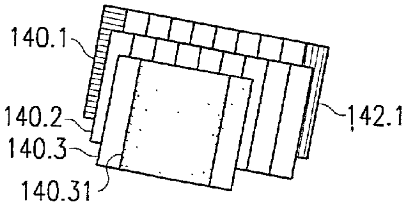


Fig. 10.11



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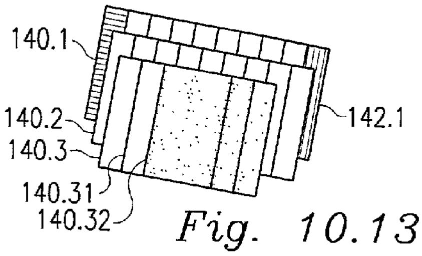

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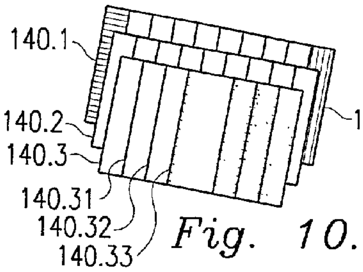

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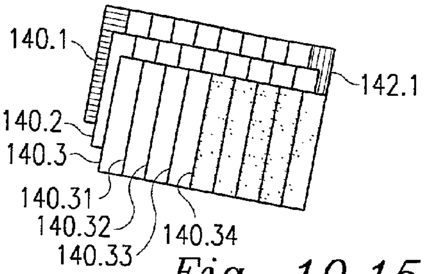

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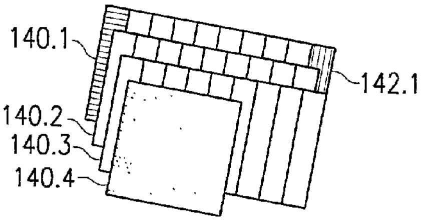

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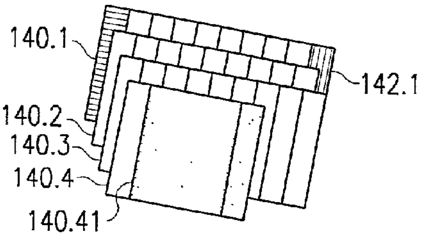

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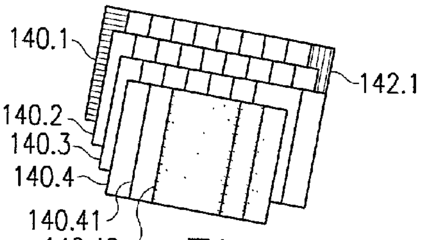

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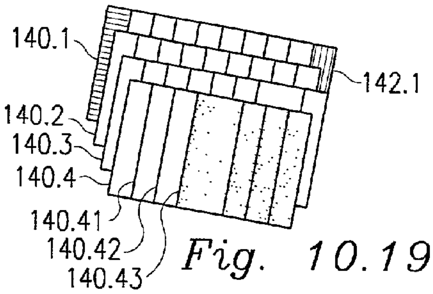

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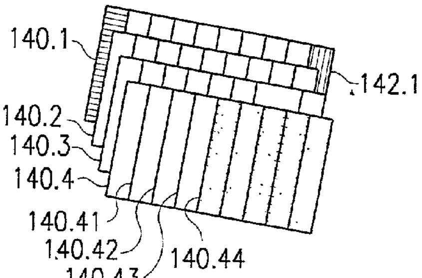
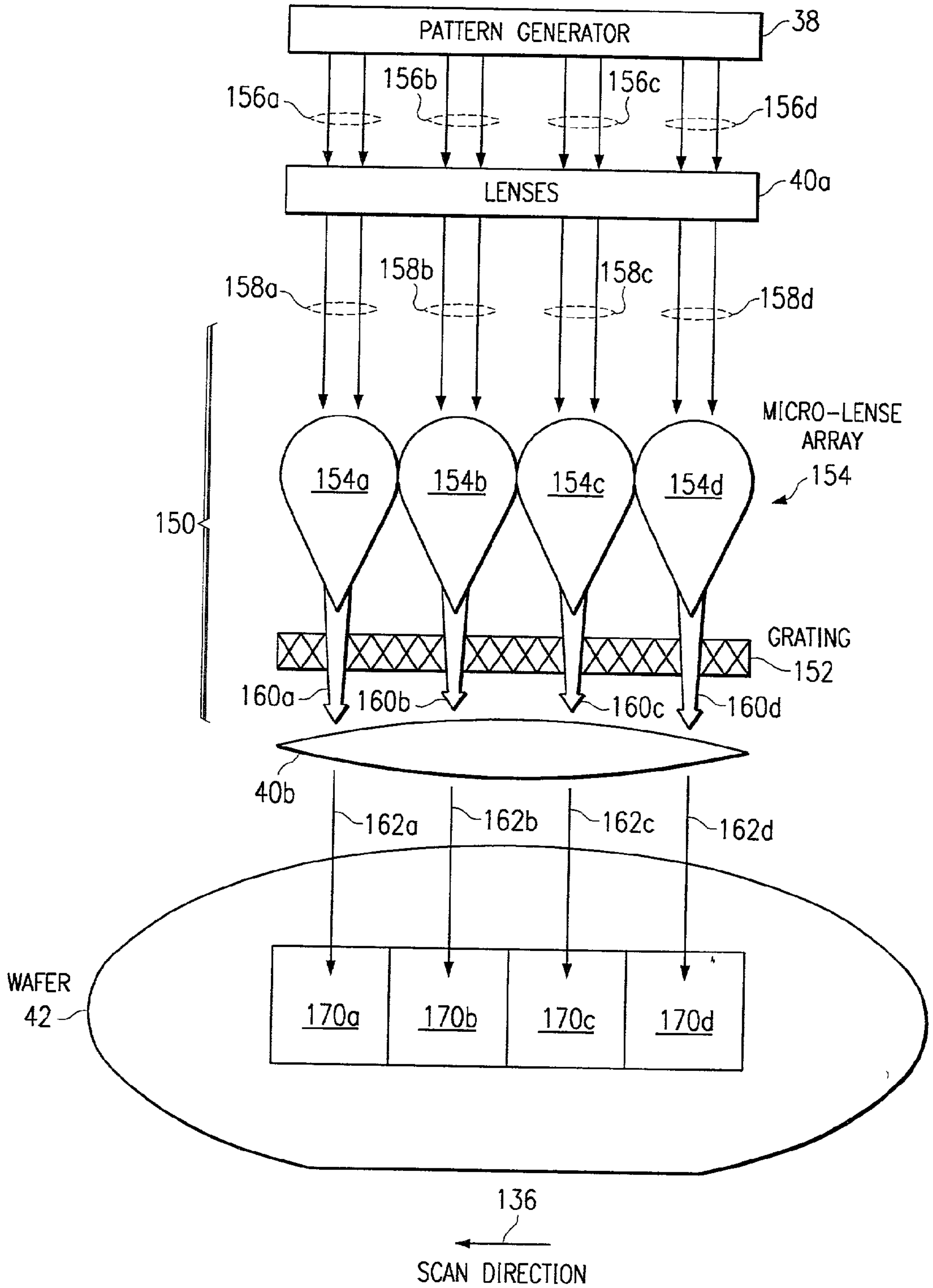


Fig. 10.20

Fig. 11


PATTERN GENERATOR
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156a
156b
156c
156d
LENSES
40a
158a
158b
158c
158d
MICRO-LENSE ARRAY
154
154a
154b
154c
154d
150
GRATING
152
160a
160b
160c
160d
40b
162a
162b
162c
162d
WAFER
42
170a
170b
170c
170d
136
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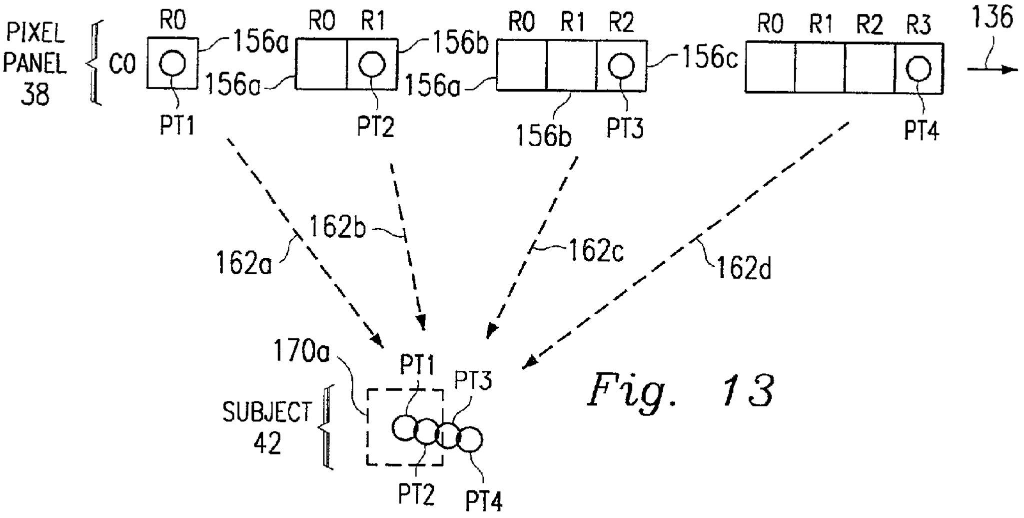
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162d
170a
SUBJECT
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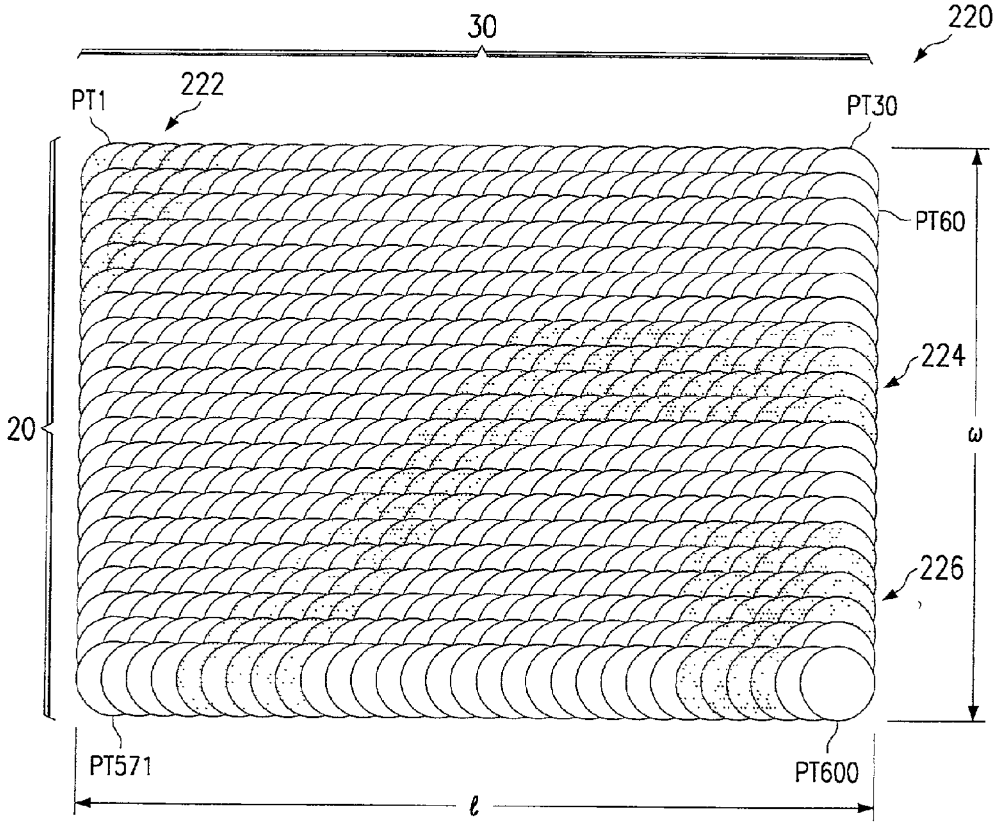
Fig. 13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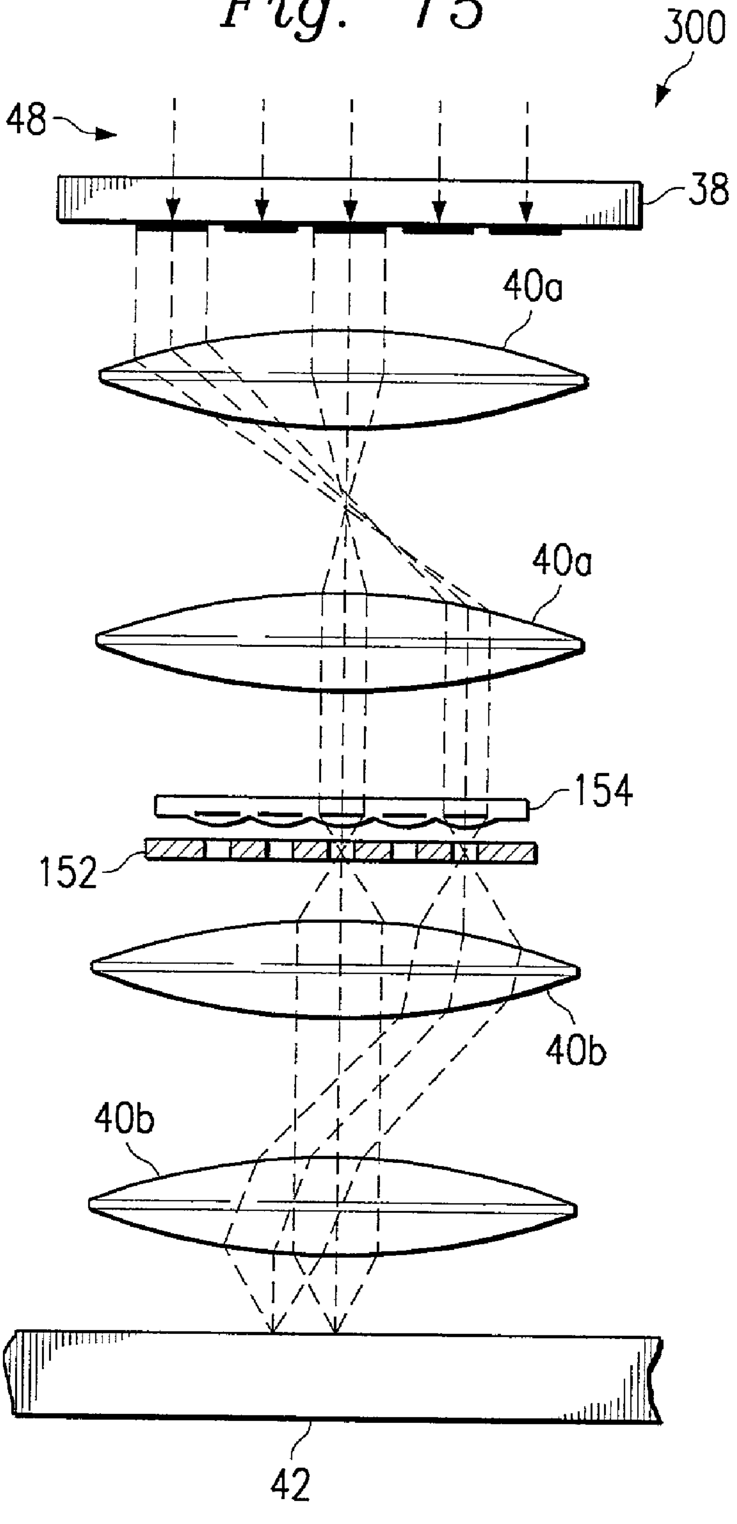
220
222
PT1
PT30
PT60
224
226
20
ω
PT571
PT600
ℓ

Fig. 14

Fig. 15



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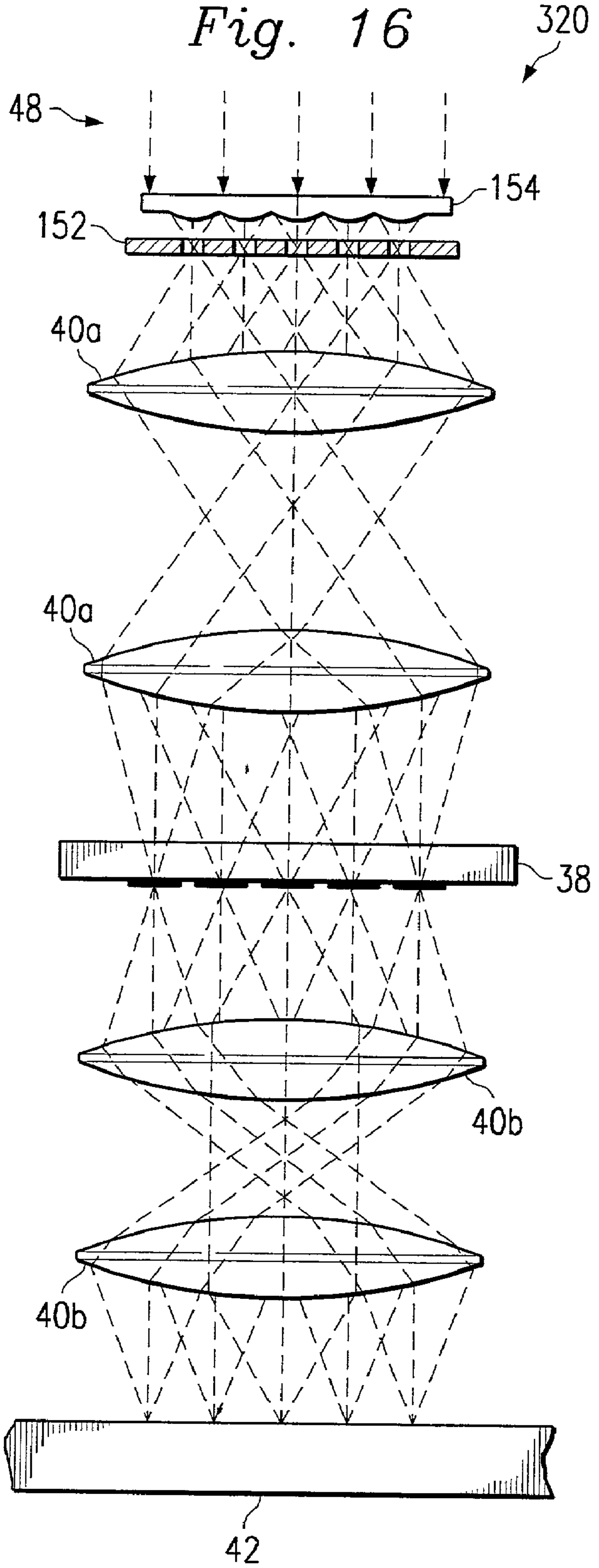

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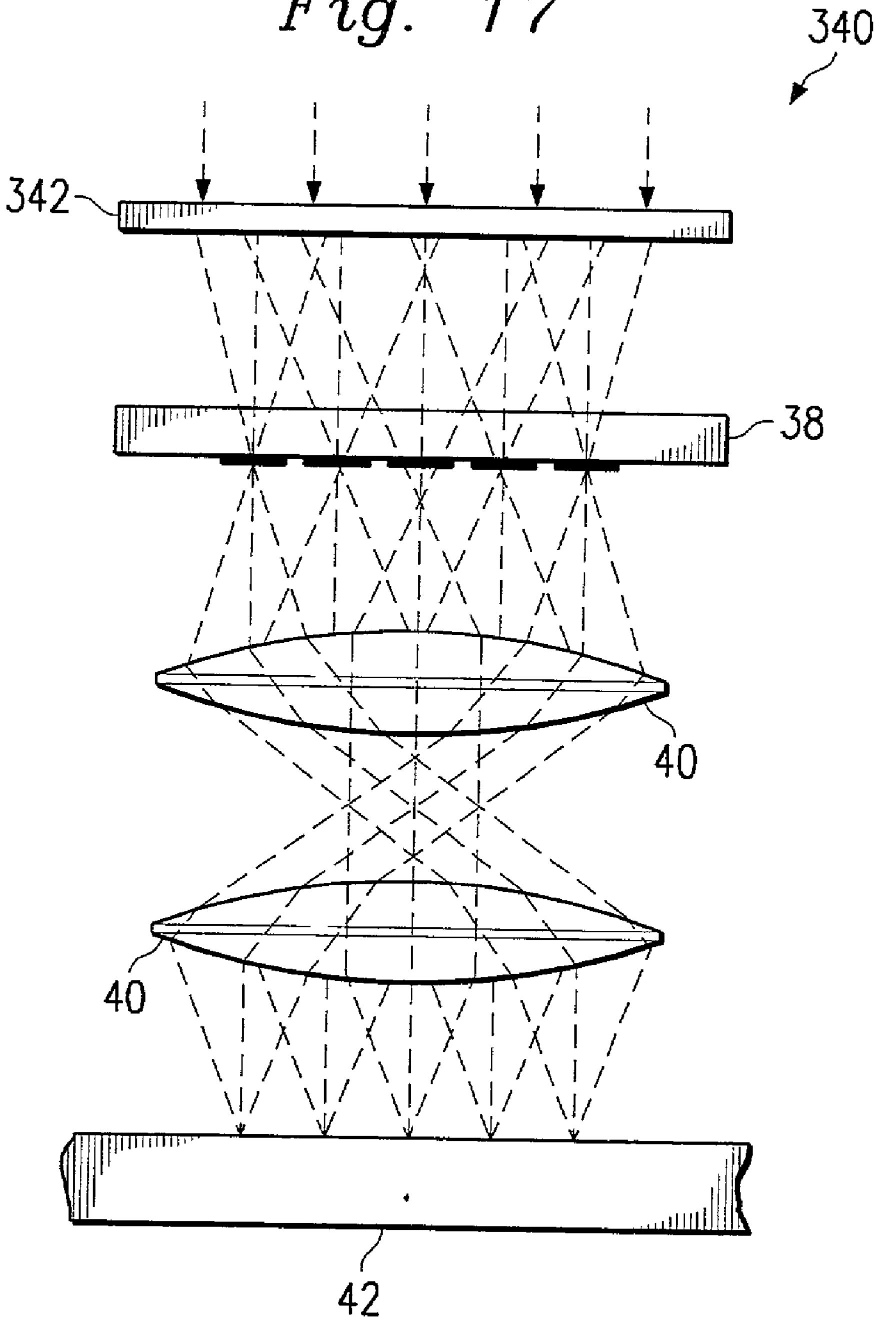

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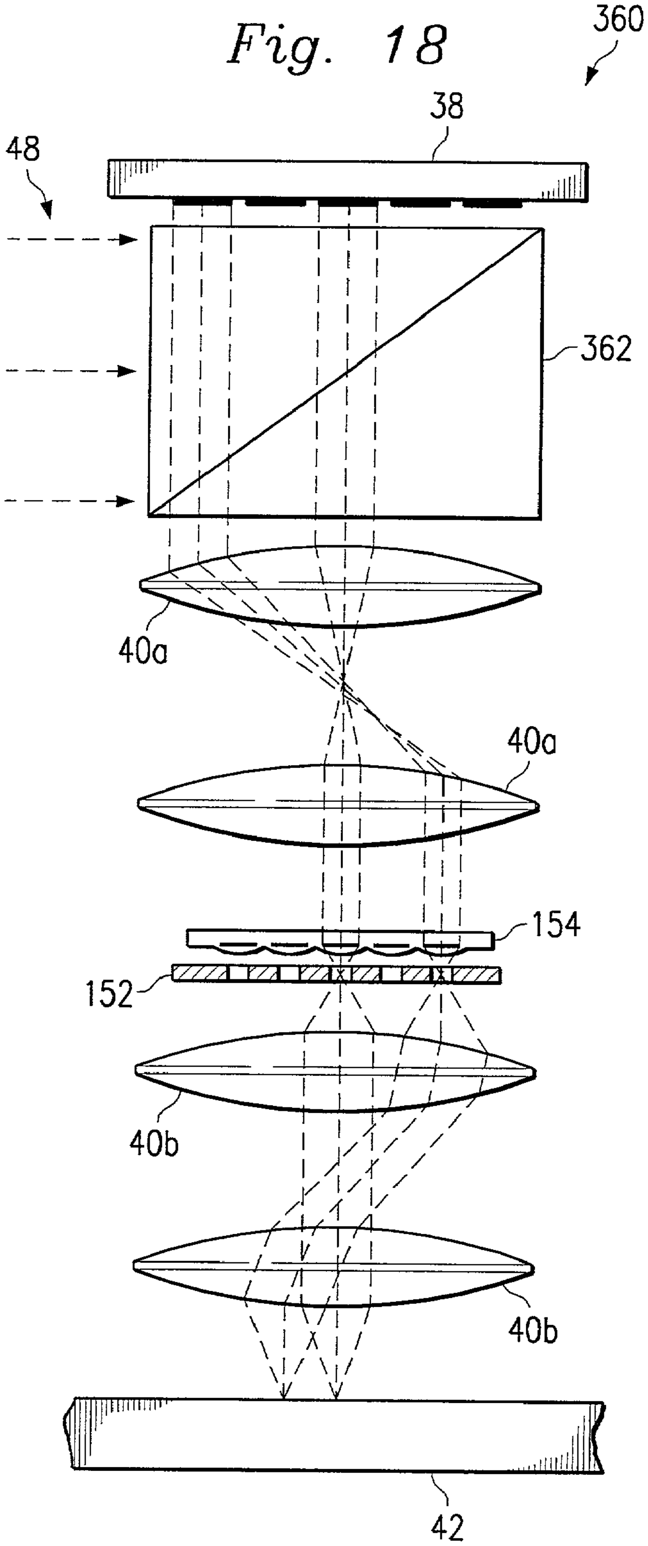

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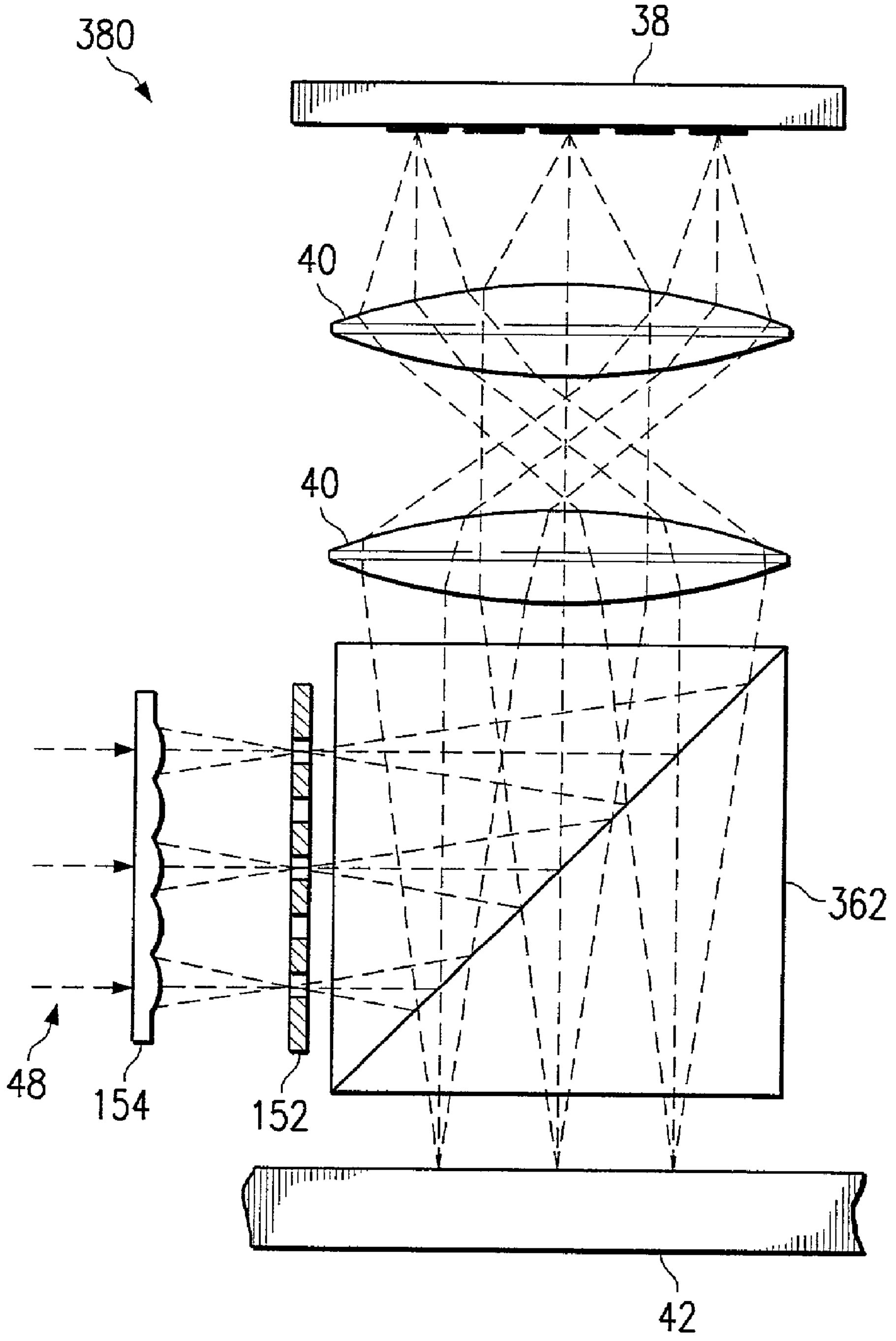


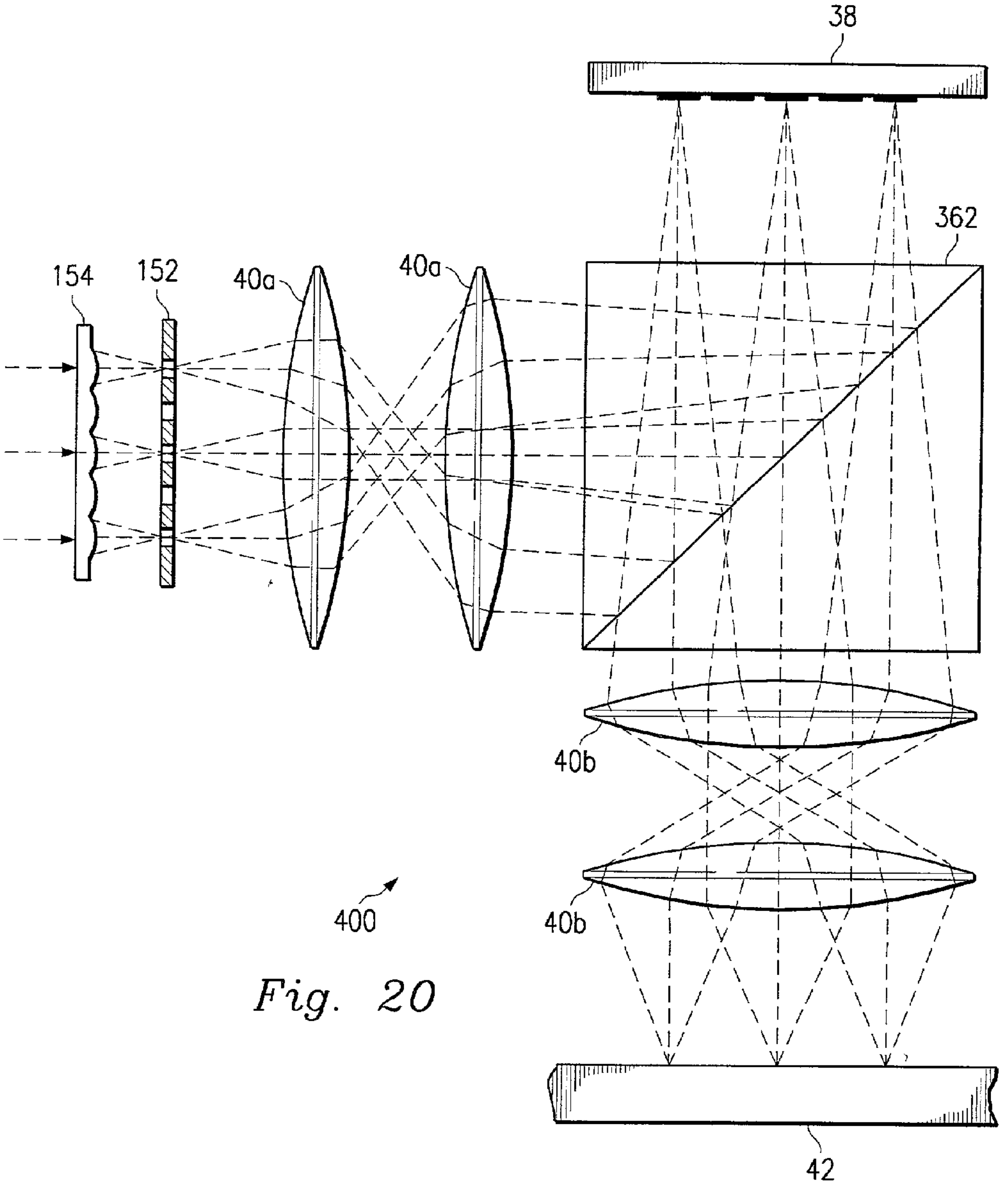


Fig. 20

Fig. 21

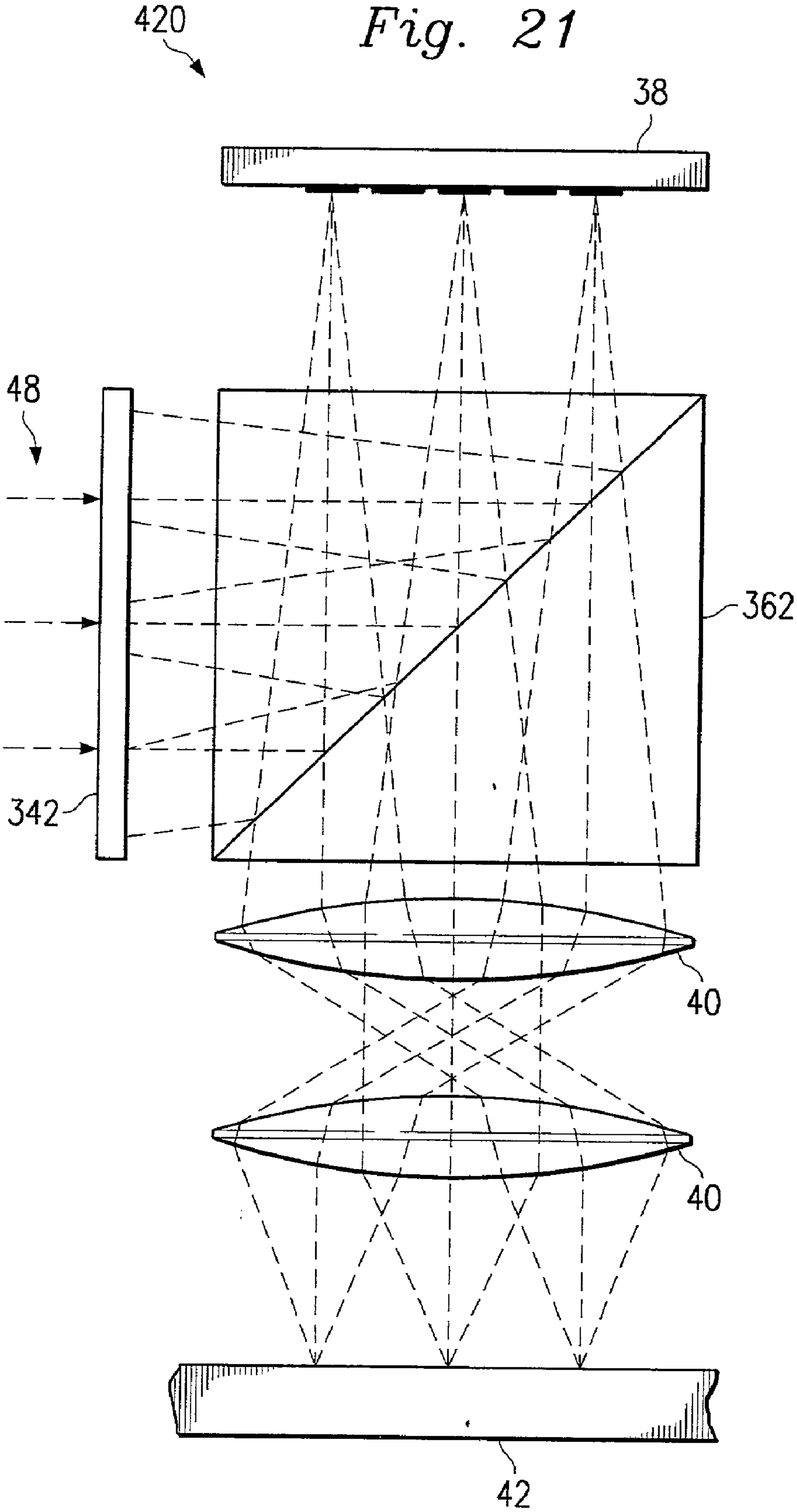


Fig. 22

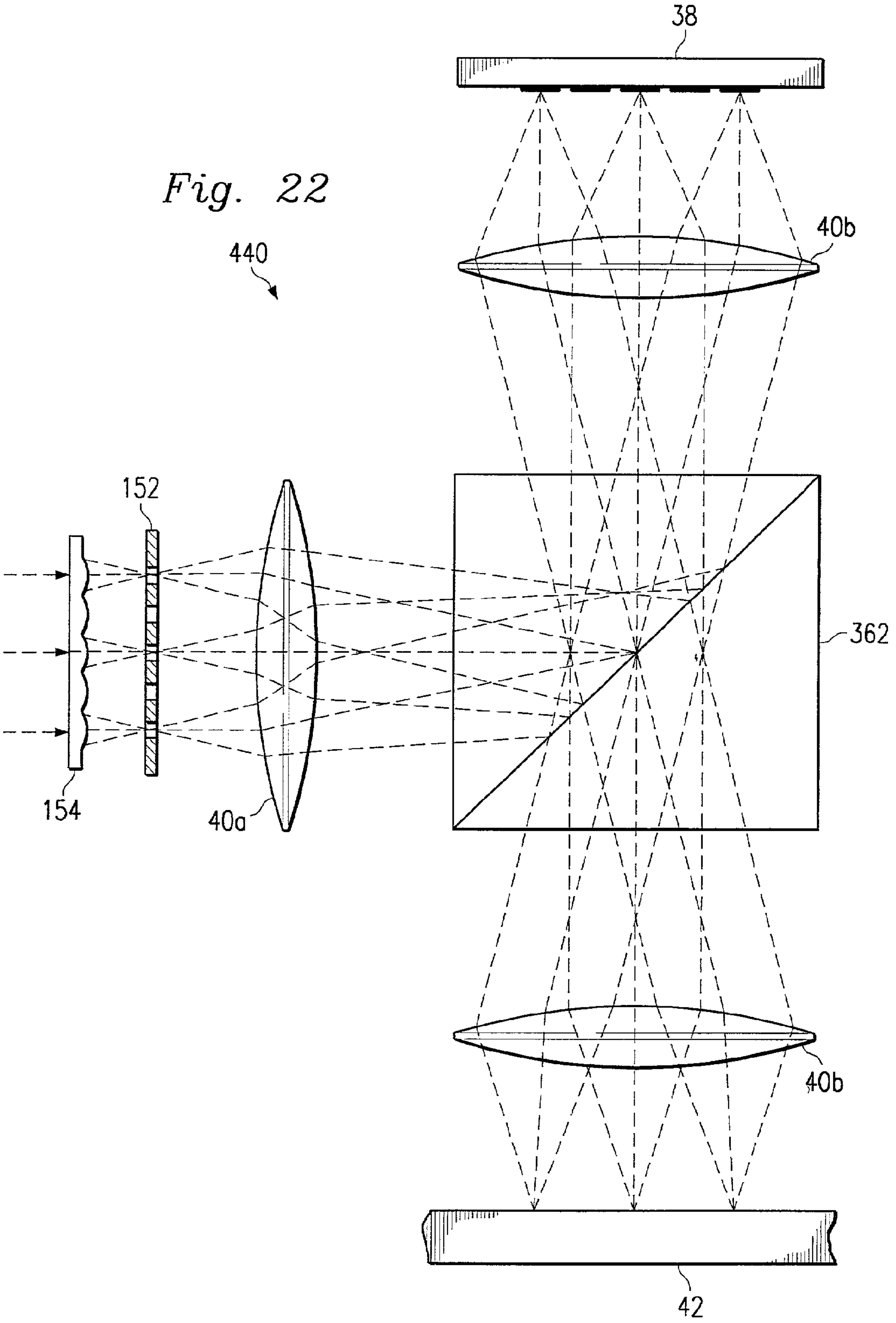


Fig. 23

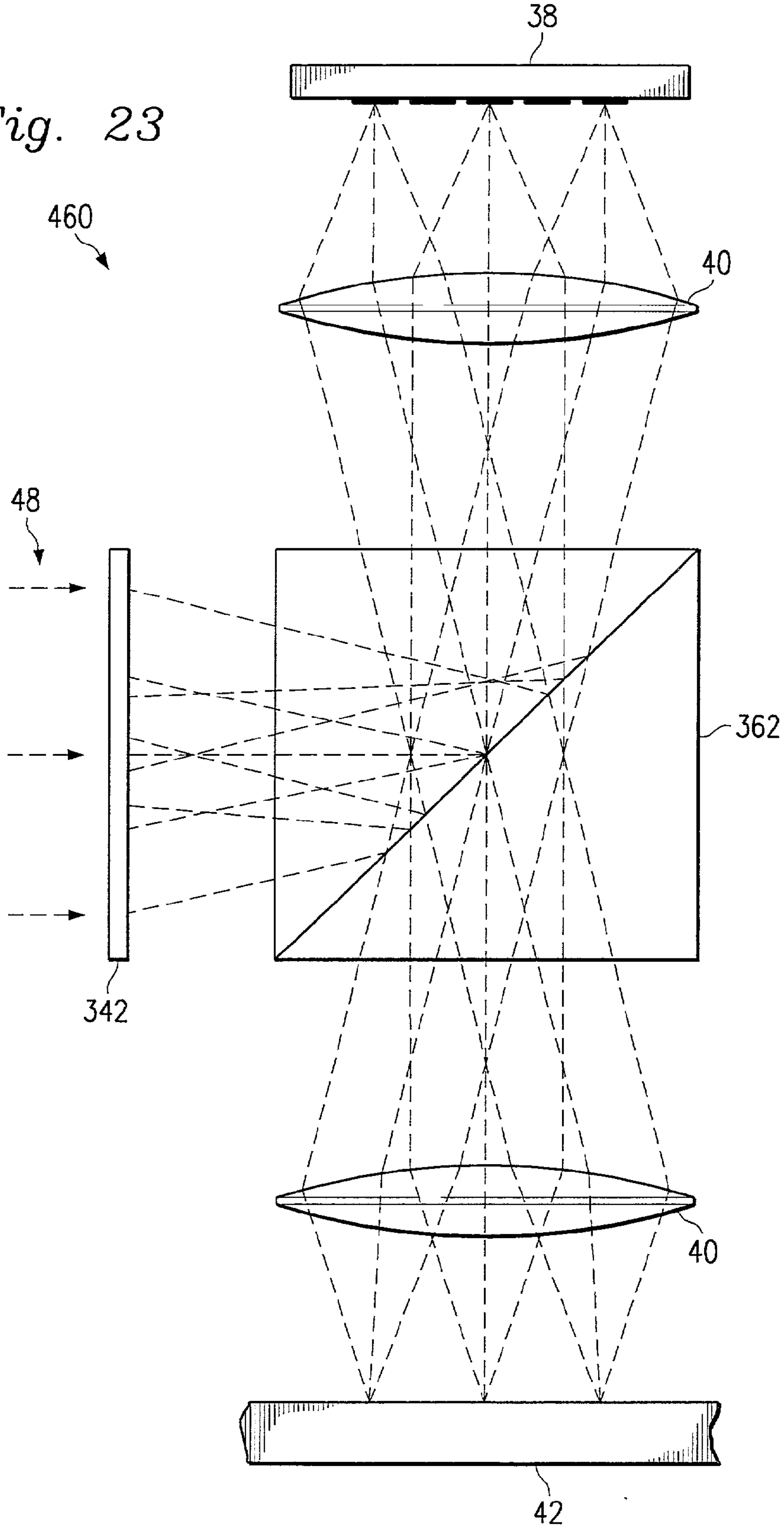


Fig. 24

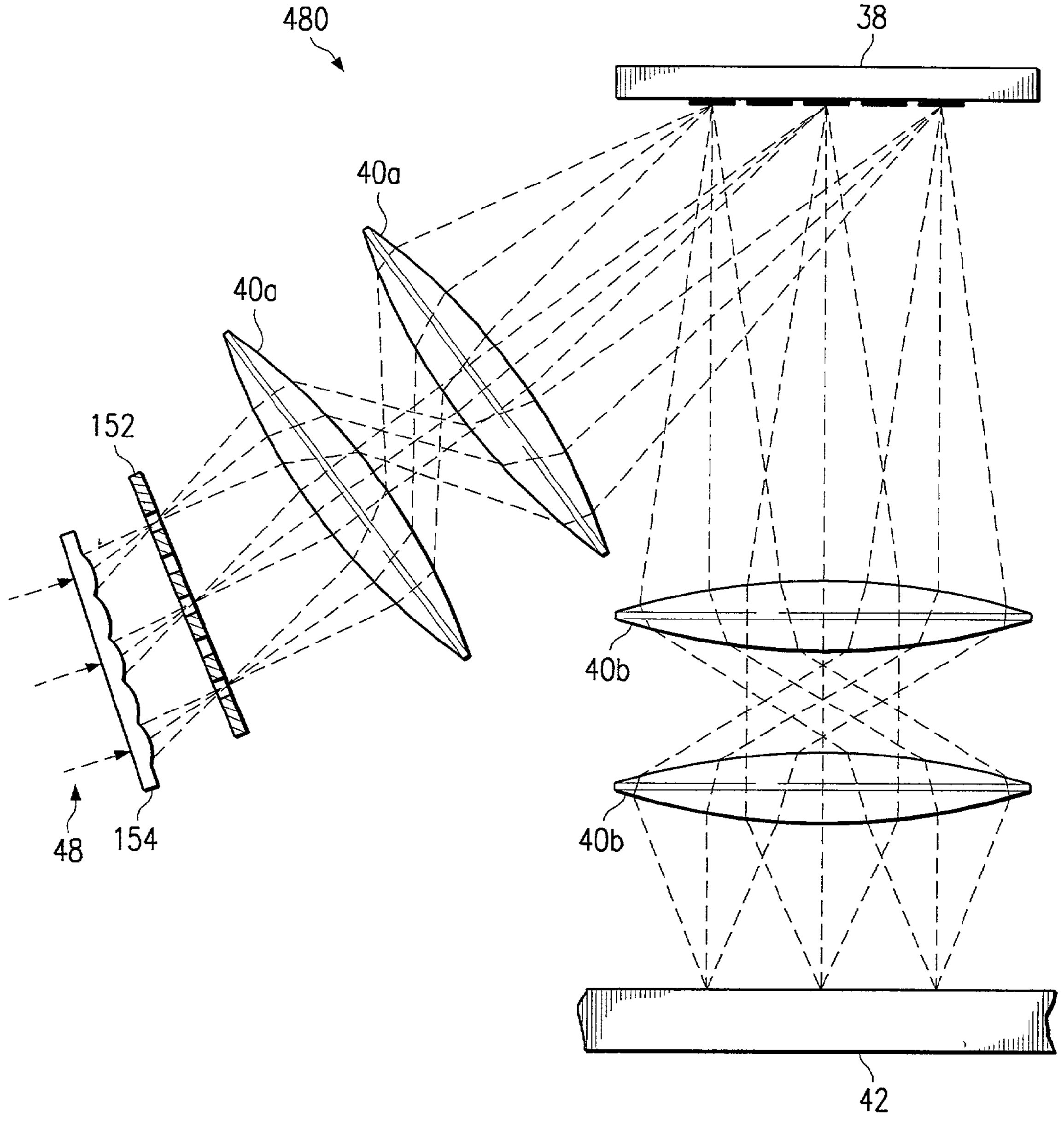
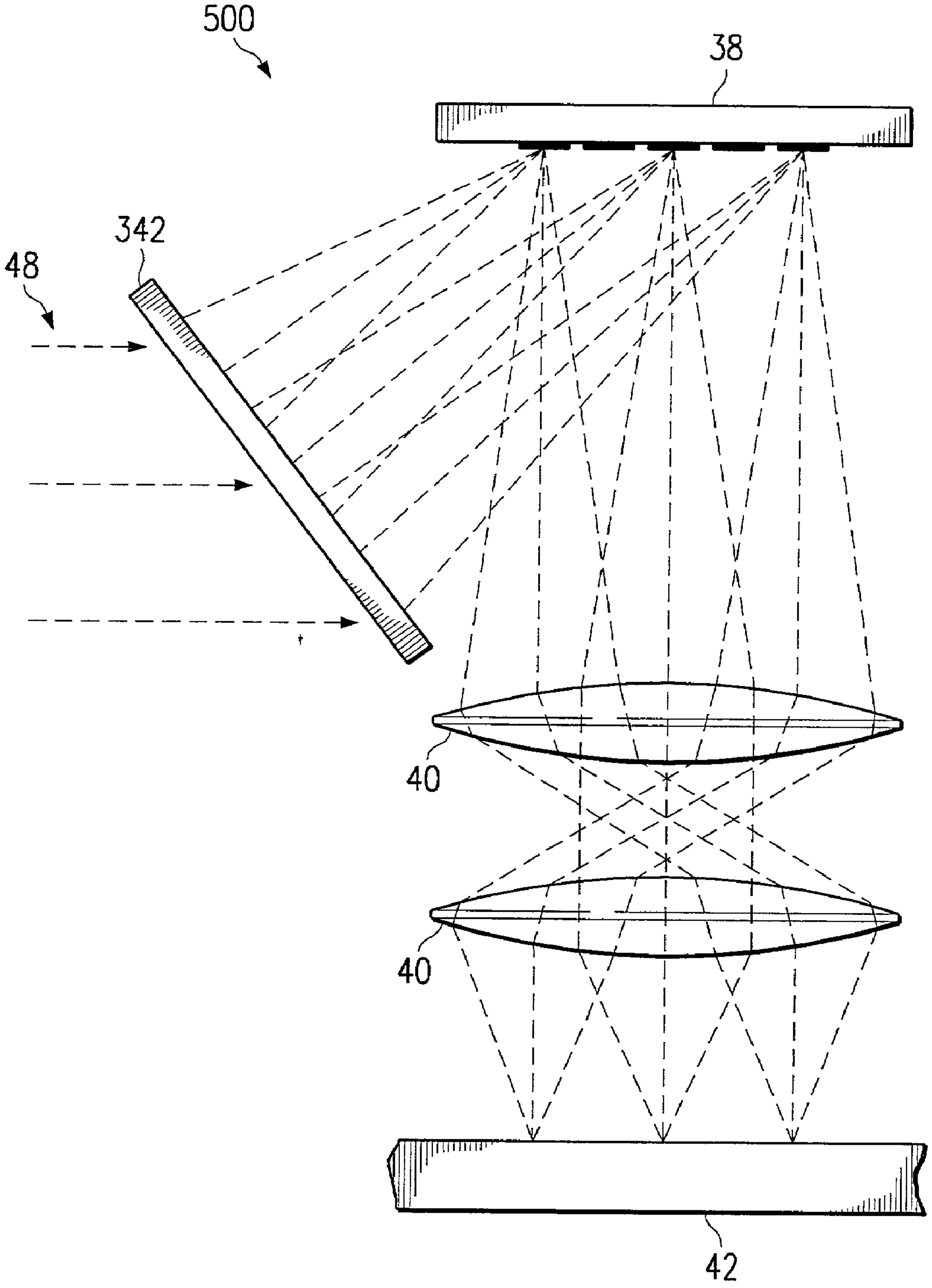


Fig. 25



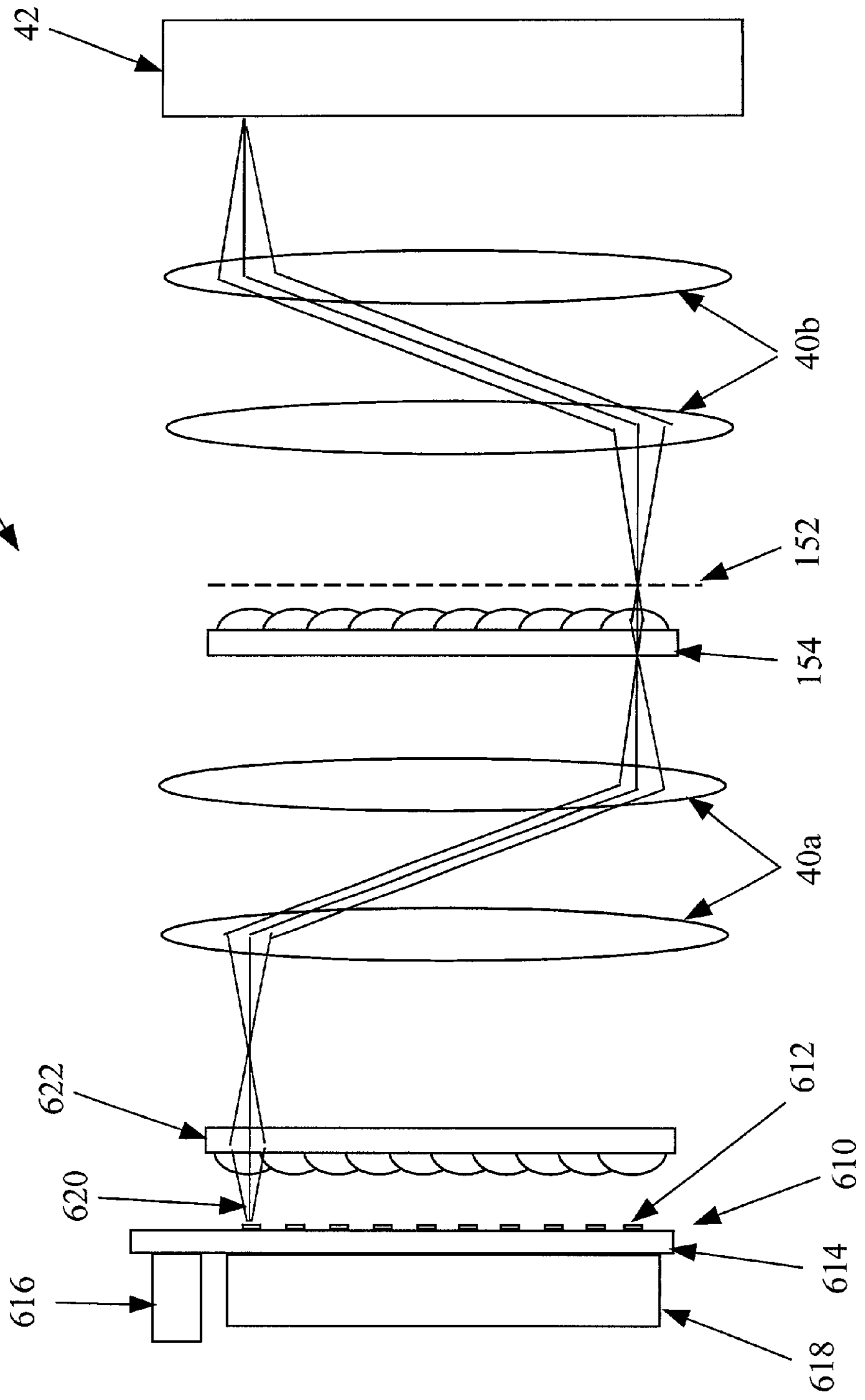


Fig. 26

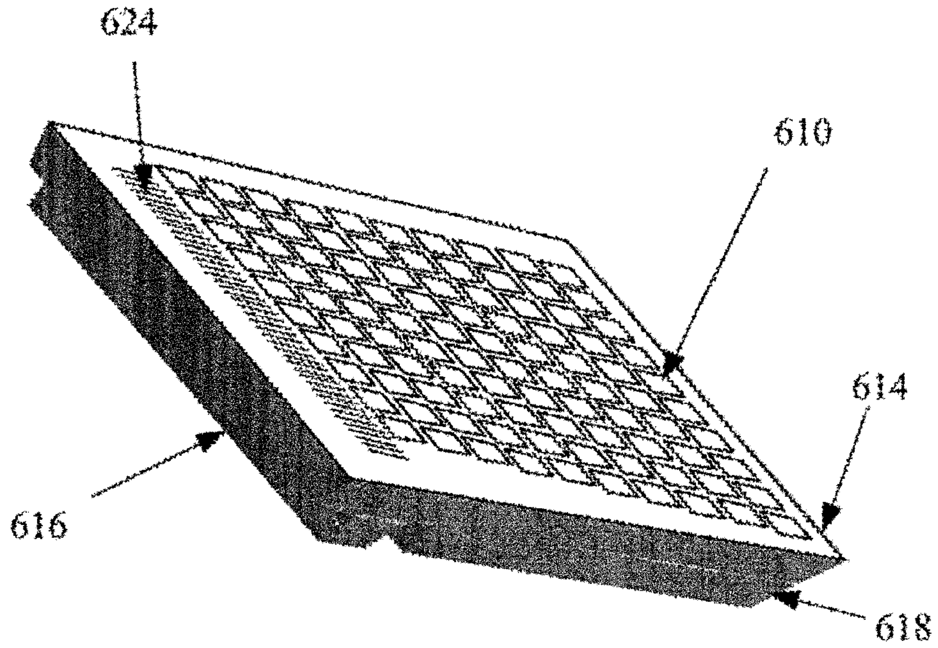


Fig. 27

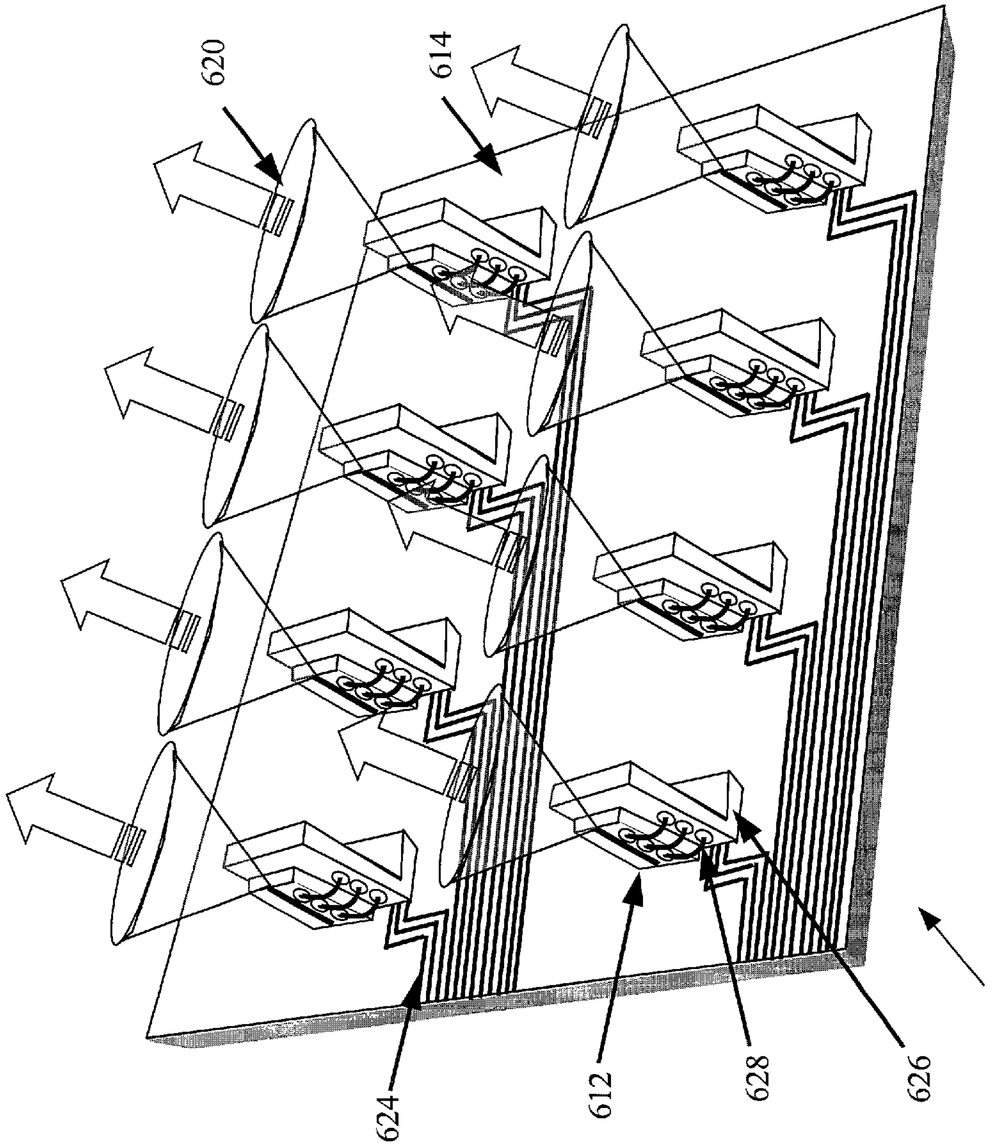


Fig. 28

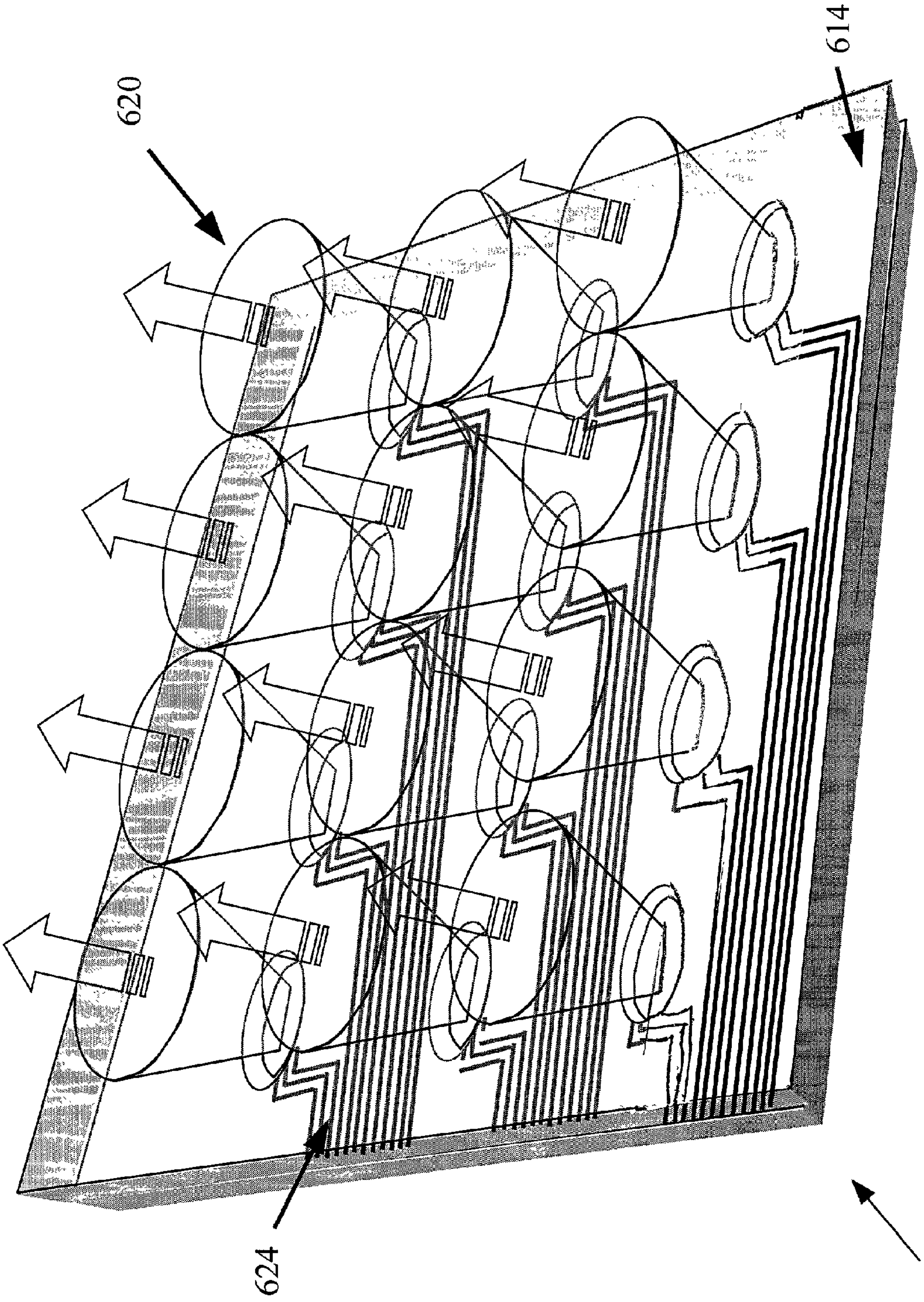


Fig. 29

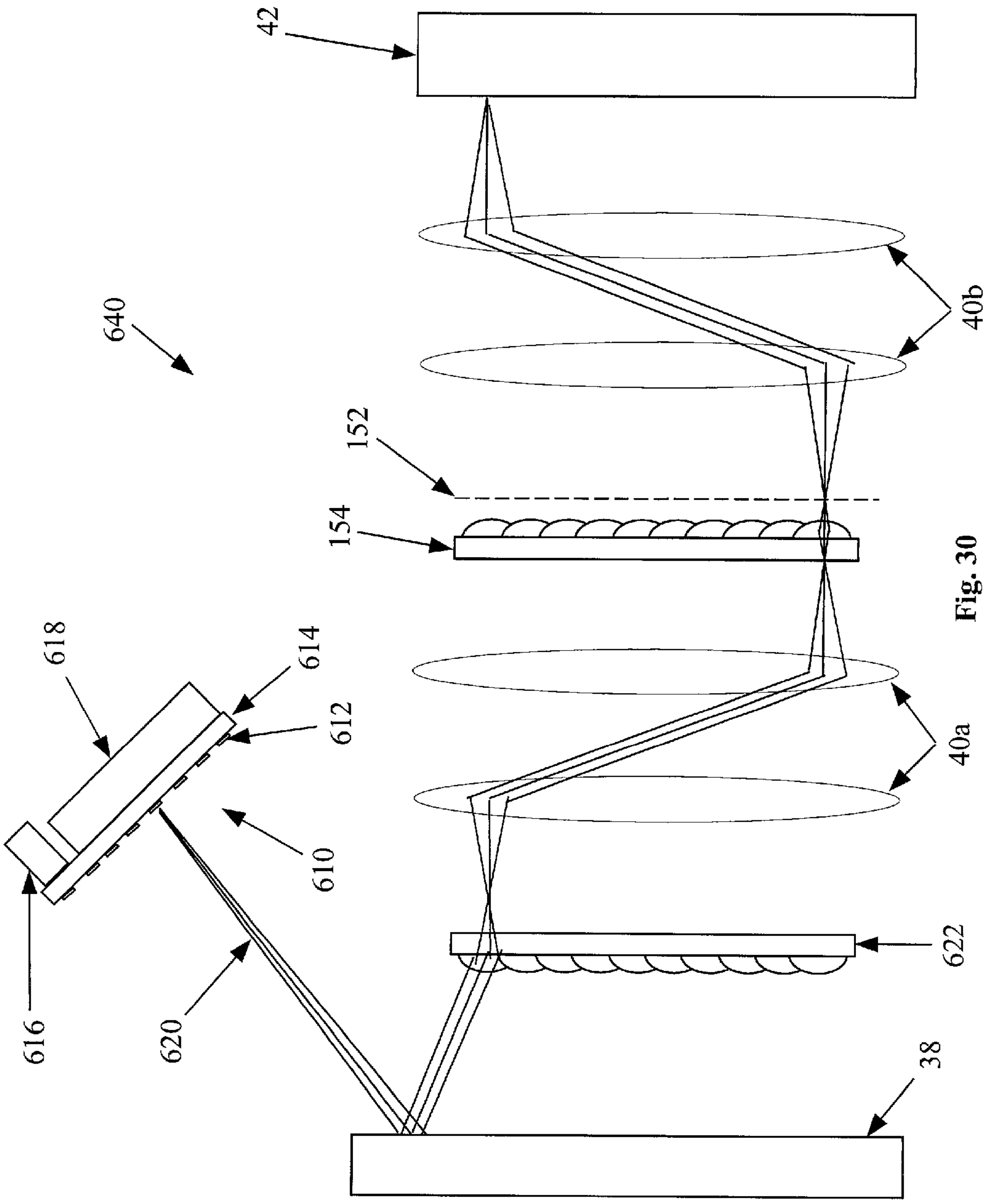


Fig. 30

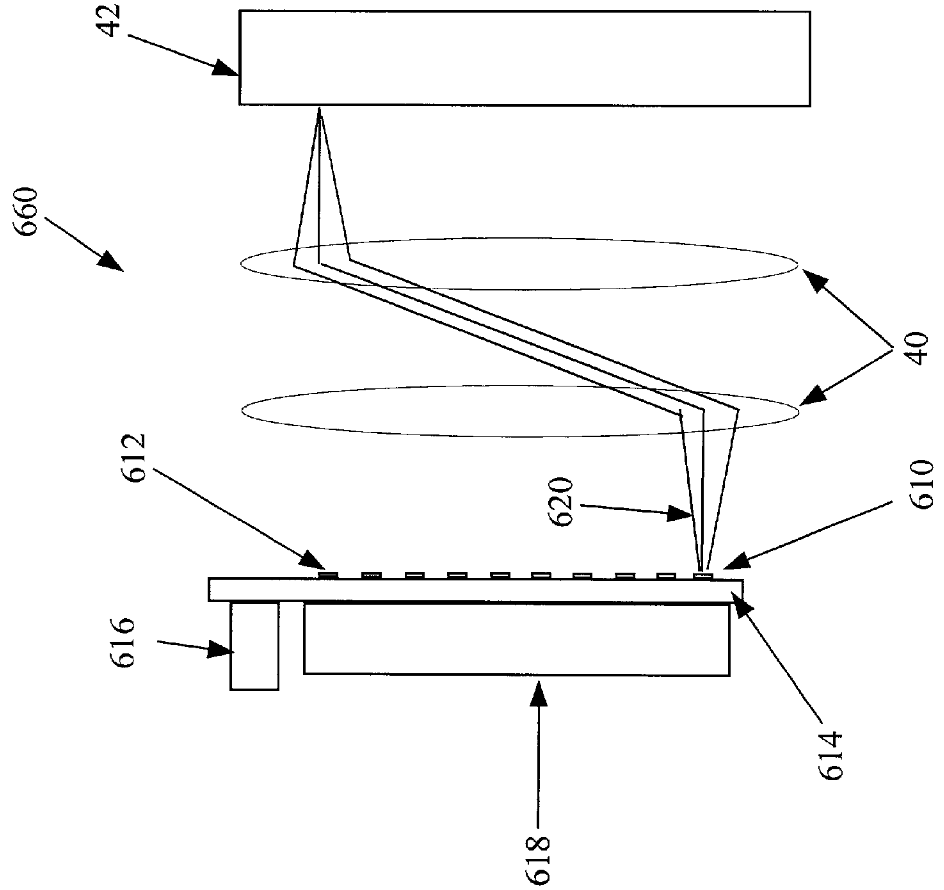


Fig. 31

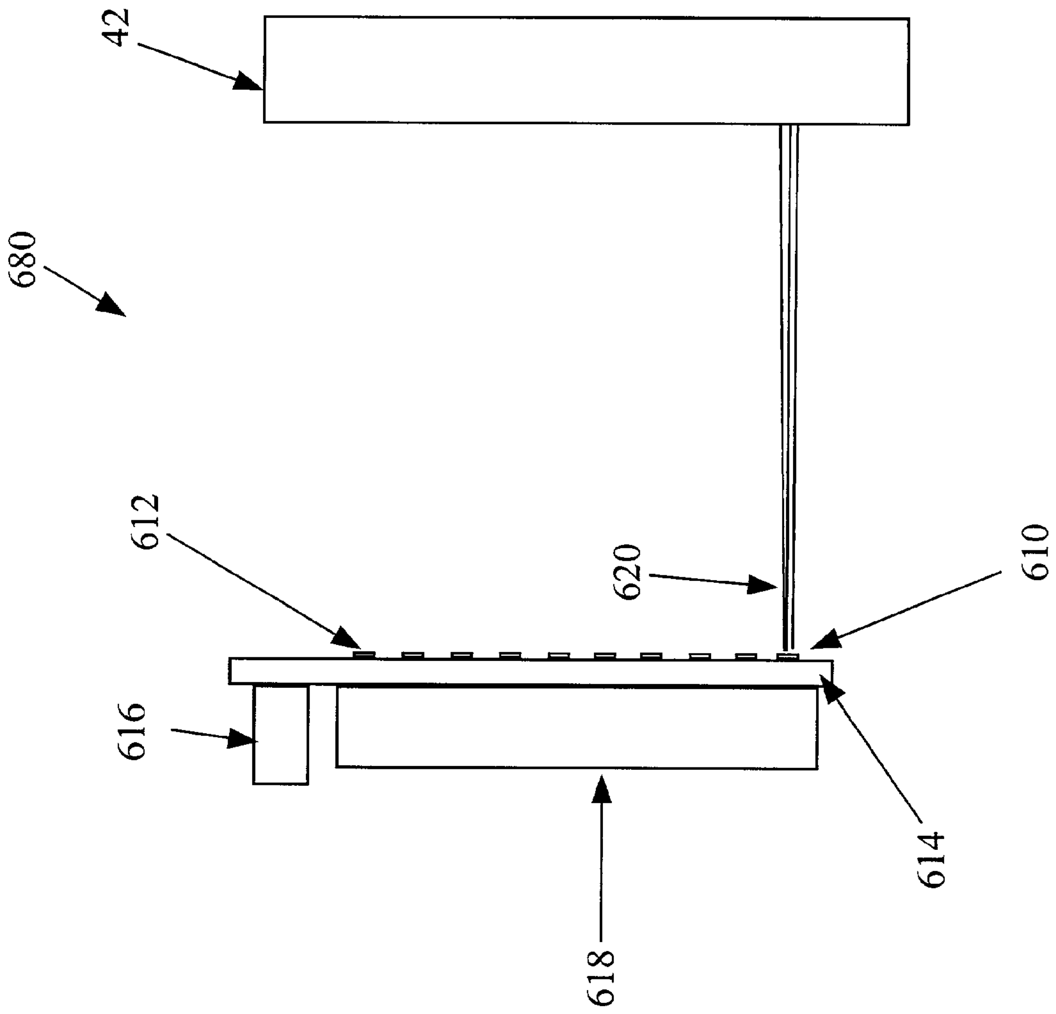


Fig. 32

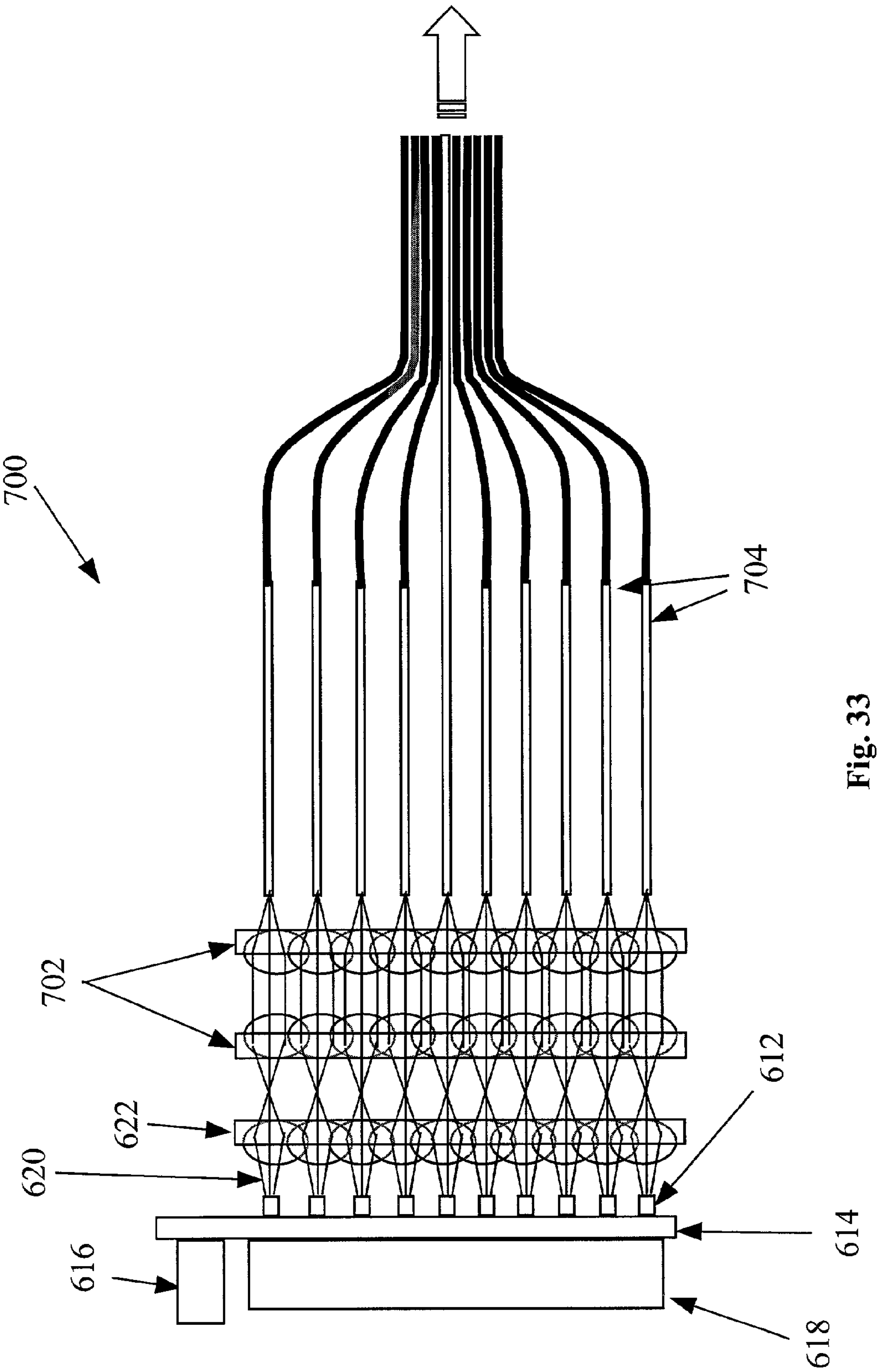


Fig. 33

INTEGRATED LASER DIODE ARRAY AND APPLICATIONS

BACKGROUND

[**0001**] The present invention relates generally to lithographic exposure equipment, and more particularly, to a photolithography system and method, such as can be used in the manufacture of semiconductor integrated circuit devices.

[**0002**] In conventional analog photolithography systems, the photographic equipment requires a mask for printing an image onto a subject. The subject may include, for example, a photo resist coated semiconductor substrate for manufacture of integrated circuits, metal substrate for etched lead frame manufacture, conductive plate for printed circuit board manufacture, or the like. A patterned mask or photomask may include, for example, a plurality of lines or structures. During a photolithographic exposure, the subject must be aligned to the mask very accurately using some form of mechanical control and sophisticated alignment mechanism.

[**0003**] U.S. Pat. No. 5,691,541, which is hereby incorporated by reference, describes a digital, reticle-free photolithography system. The digital system employs a pulsed or strobed excimer laser to reflect light off a programmable digital mirror device (DMD) for projecting a component image (e.g., a metal line) onto a substrate. The substrate is mounted on a stage that moves during the sequence of pulses.

[**0004**] U.S. patent Ser. No. 09/480,796, filed Jan. 10, 2000 and hereby incorporated by reference, discloses another digital photolithography system which projects a moving digital pixel pattern onto specific sites of a subject. A "site" may represent a predefined area of the subject that is scanned by the photolithography system with a single pixel element.

[**0005**] Both digital photolithography systems project a pixel-mask pattern onto a subject such as a wafer, printed circuit board, or other medium. The systems provide a series of patterns to a pixel panel, such as a deformable mirror device or a liquid crystal display. The pixel panel provides images consisting of a plurality of pixel elements, corresponding to the provided pattern, that may be projected onto the subject.

[**0006**] Each of the plurality of pixel elements is then simultaneously focused to different sites of the subject. The subject and pixel elements are then moved and the next image is provided responsive to the movement and responsive to the pixel-mask pattern. As a result, light can be projected onto or through the pixel panel to expose the plurality of pixel elements on the subject, and the pixel elements can be moved and altered, according to the pixel-mask pattern, to create contiguous images on the subject.

[**0007**] With reference now to **FIG. 1***a*, a conventional analog photolithography system that uses a photomask can easily and accurately produce an image **10** on a subject **12**. The image **10** can have horizontal, vertical, diagonal, and curved components (e.g., metal conductor lines) that are very smooth and of a consistent line width.

[**0008**] Referring also to **FIG. 1***b*, a conventional digital photolithography system that uses a digital mask can also produce an image **14** on a subject **16**. Although the image **14** can have horizontal, vertical, diagonal, and curved components, like the analog image **12** of **FIG. 1***a*, some of the components (e.g., the diagonal ones) are neither very smooth nor of a consistent line width.

[**0009**] Certain improvements are desired for digital photolithograph systems, such as the ones described above. For one, it is desirable to provide smooth components, such as diagonal and curved metal lines, like those produced with analog photolithography systems. In addition, it is desired to have a relatively large exposure area, to provide good image resolution, to provide good redundancy, to use a relatively inexpensive incoherent light source, to provide high light energy efficiency, to provide high productivity and resolution, and to be more flexible and reliable.

SUMMARY

[**0010**] A technical advance is provided by a novel method and system for performing digital lithography onto a subject. In one embodiment, the system includes a laser diode array for generating a digital pattern, where the array includes a plurality of laser diodes operable to project at least one laser beam. The system also includes a lens system for directing the digital pattern to the subject.

[**0011**] In another embodiment, the laser diode array is combined with the lens system to form a single unit. In yet another embodiment, the system includes a pixel panel and the laser diode array serves as a light source for the pixel panel. In still another embodiment, the system includes a lens array for reshaping the beam.

BRIEF DESCRIPTION OF THE DRAWINGS

[**0012**] **FIGS. 1***a* and **1***b* are images produced by a conventional analog photolithography system and a conventional digital photolithography system, respectively.

[**0013**] **FIG. 2** is a block diagram of an improved digital photolithography system for implementing various embodiments of the present invention.

[**0014**] **FIGS. 3***a* and **3***b* illustrate various overlay arrangement of pixels being exposed on a subject.

[**0015**] **FIGS. 4***a* and **4***b* illustrate the effect of overlaid pixels on the subject.

[**0016**] **FIG. 5** illustrates a component exposure from the system of **FIG. 2**, compared to conventional exposures from the systems of **FIGS. 1***b* and **1***a*.

[**0017**] **FIGS. 6***a* and **6***b* illustrate component exposures, corresponding to the images of **FIGS. 1***a* and **1***b*, respectively.

[**0018**] **FIG. 7** illustrates various pixel patterns being provided to a pixel panel of the system of **FIG. 2**.

[**0019**] **FIGS. 8, 9**, and **10.1-10.20** provide diagrams of a subject that is positioned and scanned at an angle on a stage. The angle facilitates the overlapping exposure of a site on the subject according to one embodiment of the present invention.

[**0020**] **FIG. 11** is a block diagram of a portion of the digital photolithography system of **FIG. 2** for implementing additional embodiments of the present invention FIGS.

12-13 provide diagrams of a subject that is positioned and scanned at an angle on a stage and being exposed by the system of **FIG. 11**.

[**0021**] **FIG. 14** illustrates a site that has been overlapping exposed 600 times.

[**0022**] FIGS. **15-25** are block diagrams of several different digital photolithography systems for implementing various embodiments of the present invention.

[**0023**] **FIG. 26** is a block diagram illustrating a digital photolithography system utilizing a laser diode array for implementing various embodiments of the present invention.

[**0024**] **FIG. 27** illustrates an exemplary laser diode array that may be used in the system of **FIG. 26**.

[**0025**] **FIG. 28** illustrates a macrostructure embodiment of the laser diode array of **FIG. 27**.

[**0026**] **FIG. 29** illustrates a microstructure embodiment of the laser diode array of **FIG. 27**.

[**0027**] FIGS. **30-32** are block diagrams of several different digital photolithography systems for implementing various embodiments of the present invention.

[**0028**] **FIG. 33** is a block diagram illustrating an implementation of the present invention as a high power light source.

DETAILED DESCRIPTION

[**0029**] The present disclosure relates to exposure systems, such as can be used in semiconductor photolithographic processing. It is understood, however, that the following disclosure provides many different embodiments, or examples, for implementing different features of the invention. Specific examples of components and arrangements are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to limit the invention from that described in the claims.

[**0030**] Maskless Photolithography System

[**0031**] Referring now to **FIG. 2, a** maskless photolithography system **30** includes a light source **32**, a first lens system **34**, a computer aided pattern design system **36**, a pixel panel **38**, a panel alignment stage **39**, a second lens system **40**, a subject **42**, and a subject stage **44**. A resist layer or coating **46** may be disposed on the subject **42**. The light source **32** may be an incoherent light source (e.g., a Mercury lamp) that provides a collimated beam of light **48** which is projected through the first lens system **34** and onto the pixel panel **38**.

[**0032**] The pixel panel **38** is provided with digital data via suitable signal line(s) **50** from the computer aided pattern design system **36** to create a desired pixel pattern (the pixel-mask pattern). The pixel-mask pattern may be available and resident at the pixel panel **38** for a desired, specific duration. Light emanating from (or through) the pixel-mask pattern of the pixel panel **38** then passes through the second lens system **40** and onto the subject **42**. In this manner, the pixel-mask pattern is projected onto the resist coating **46** of the subject **42**.

[**0033**] The computer aided mask design system **36** can be used for the creation of the digital data for the pixel-mask pattern. The computer aided pattern design system **36** may include computer aided design (CAD) software similar to that which is currently used for the creation of mask data for use in the manufacture of a conventional printed mask. Any modifications and/or changes required in the pixel-mask pattern can be made using the computer aided pattern design system **36**. Therefore, any given pixel-mask pattern can be changed, as needed, almost instantly with the use of an appropriate instruction from the computer aided pattern design system **36**. The computer aided mask design system **36** can also be used for adjusting a scale of the image or for correcting image distortion.

[**0034**] In the present embodiment, the pixel panel **38** is a digital light processor (DLP) or digital mirror device (DMD) such as is illustrated in U.S. Pat. No. 5,079,544 and patents referenced therein. Current DMD technology provides a 600×800 array of mirrors for a set of potential pixel elements. Each mirror can selectively direct the light **48** towards the subject **42** (the "ON" state) or away from the subject (the "OFF" state). Furthermore, each mirror can alternate between ON and OFF for specific periods of time to accommodate variations in light efficiency. For example, if the second lens system **40** has a "darker" area (e.g., a portion of the lens system is inefficient or deformed), the DMD can alternate the mirrors corresponding with the "brighter" areas of the lens, thereby equalizing the overall light energy projected through the lens. For the sake of simplicity and clarity, the pixel panel **38** will be further illustrated as one DMD. Alternate embodiments may use multiple DMDs, one or more liquid crystal displays and/or other types of digital panels.

[**0035**] In some embodiments, the computer aided mask design system **36** is connected to a first motor **52** for moving the stage **44**, and a driver **54** for providing digital data to the pixel panel **38**. In some embodiments, an additional motor **55** may be included for moving the pixel panel, as discussed below. The system **36** can thereby control the data provided to the pixel panel **38** in conjunction with the relative movement between the pixel panel **38** and the subject **42**.

[**0036**] Pixel Overlay

[**0037**] The amount of exposure time, or exposure intensity, of light from the pixel panel **38** directly affects the resist coating **46**. For example, if a single pixel from the pixel panel **38** is exposed for a maximum amount of time onto a single site of the subject **42**, or for a maximum intensity, then the corresponding portion of resist coating **46** on the subject would have a maximum thickness (after non-exposed or under exposed resist has been removed). If the single pixel from the pixel panel **38** is exposed for less than the maximum amount of time, or at a reduced intensity, the corresponding portion of resist coating **46** on the subject **42** would have a moderate thickness. If the single pixel from the pixel panel **38** is not exposed, then the corresponding portion of resist coating **42** on the subject **42** would eventually be removed.

[**0038**] Referring now to **FIGS. 3***a* and **3***b*, it is desired that each pixel element exposed onto a site overlap previous pixel element exposures. **FIG. 3***a* shows a one-direction overlay scenario where a pixel element **80.1** is overlapped by pixel element **80.2**, which is overlapped by pixel element **80.3**, . . . which is overlapped by pixel element **80**.N, where "N" is the total number of overlapped pixel elements in a single direction. It is noted that, in the present example, pixel element **80**.1 does not overlay pixel element **80**.N.

[**0039**] **FIG. 3***b* is a two-dimensional expansion **FIG. 3***a*. In this example, pixel element **80**.1 is overlapped in another direction by pixel element **81**.1, which is overlapped by pixel element **82**.1, . . . which is overlapped by pixel element **8**M.N, where "M" is the total number of overlapped pixel elements in a second direction. As a result, a total of M×N pixel elements can be exposed for a single site.

[**0040**] Referring now to **FIG. 4***a*, consider for example a site that has the potential to be exposed by (M,N)=(4,4) pixel elements. In this example, only four of the 16 possible pixel elements are actually "ON", and therefore expose portions of the subject **42**. These four pixel elements are designated: **100**.1, **100**.2, **100**.3, **100**.4. The four pixel elements **100**.1-**100**.4 are exposed onto the photo resist **46** of the subject **42**. All four pixel elements **100**.1-**100**.4 overlap with each other at an area **102**; three of the pixel elements overlap at an area **104**; two of the pixel elements overlap at an area **106**; and an area **108** is only exposed by one pixel element. Accordingly, area **102** will receive maximum exposure (100%); area **104** will receive 75% exposure; area **106** will receive **50**% exposure; and area **108** will receive **25**% exposure. It is noted that the area **102** is very small, 1/16th the size of any pixel element **100**.1-**100**.4 in the present example.

[**0041**] Referring now to **FIG. 4***b*, the example of **FIG. 4***a* can be expanded to (M,N)=(6,6) pixel elements, with two more overlapping pixel elements **100**.5, **100**.6 in the ON state. The pixel elements **100**.5, **100**.6 are therefore exposed onto the photo resist **46** of the subject **42** so that they overlap some of the four pixel elements **100**.1-**100**.4. In this expanded example, the pixel elements **100**.1-**100**.4 overlap with each other at area **102**; the four pixel elements **100**.2-**100**.5 overlap each other at an area **110**; and the four pixel elements **100**.3-**100**.6 overlap each other at an area **112**. In addition, area **114** will receive 75% exposure; area **116** will receive 50% exposure; and area **118** will receive 25% exposure. As a result, a very small ridge is formed on the photo resist **46**.

[**0042**] In one embodiment, the pixel panel **32** of the present invention may have a 600×800 array of pixel elements. The overlapping is defined by the two variables: (M,N). Considering one row of 600 pixels, the system overlaps the 600 pixels onto an overlay area **184** of:

$$(M,N)=20\ \text{pixels}\times 30\ \text{pixels}. \qquad (1)$$

[**0043**] Referring also to **FIG. 5***a*, the process of **FIGS. 4***a* and **4***b* can be repeated to produce a diagonal component **150** on the subject **42**. Although the example of **FIGS. 4***a* and **4***b* have only four potential degrees of exposure (100%, 75%, 50%, 25%), by increasing the number of overlaps (such as is illustrate in **FIG. 3***b*), it is possible to have a very fine resolution of desired exposure.

[**0044**] The diagonal component **120** appears as a prism-shaped structure having a triangular cross-section. If the subject **42** is a wafer, the component **120** may be a conductor (e.g., a metal line), a section of poly, or any other structure. The top most portion **120***t* of the component is the portion of photo resist **46** that is overlapped the most by corresponding pixel elements, and therefore received the maximum exposure.

[**0045**] The component **120** is contrasted with a component **122** of **FIG. 5***b* and a component **124** of **FIG. 5***c*. The component **122** of **FIG. 5***b* illustrates a conventional digital component. The component **124** of **FIG. 5***c* illustrates a conventional analog component.

[**0046**] Overlay Methods

[**0047**] Referring again to **FIG. 2**, the above-described overlays can be implemented by various methods. In general, various combinations of moving and/or arranging the pixel panel **38** and/or the subject **42** can achieve the desired overlap.

[**0048**] In one embodiment, the maskless photolithography system **30** performs two-dimensional digital scanning by rapidly moving the image relative to the subject in two directions (in addition to the scanning motion). The panel motor **55** is attached to the pixel panel **38** to move the pixel panel in two directions, represented by an x-arrow **132** and a y-arrow **134**. The panel motor **55** may be a piezo electric device (PZT) capable of making very small and precise movements.

[**0049**] In addition, the scanning motor **55** scans the stage **44**, and hence the subject **42**, in a direction **136**. Alternatively, the stage **44** can be fixed and the panel motor **55** can scan the pixel panel **38** (and the lenses **40**) opposite to direction **136**.

[**0050**] Referring also to **FIG. 7**, corresponding to the image scanning described above, the pixel-mask pattern being projected by the pixel panel **38** changes accordingly. This correspondence can be provided, in one embodiment, by having the computer system **36** (**FIG. 2**) control both the scanning movement **70** and the data provided to the pixel panel **38**. The illustrations of **FIG. 7** and the following discussions describe how the data can be timely provided to the pixel panel.

[**0051**] **FIG. 7** shows three intermediate patterns of pixel panel **38**. Since the pattern on the pixel panel **38** and the data on the signal lines **50** change over time, the corresponding patterns on the pixel panel and data on the signal lines at a specific point in time are designated with a suffix ".1", ".2", or ".3". In the first intermediate pattern, the pattern of pixel panel **38**.1 is created responsive to receiving data DO provided through the signal lines **50**.1. In the present example, the pattern is created as a matrix of pixel elements in the pixel panel **38**.1. After a predetermined period of time (e.g., due to exposure considerations being met), the pattern is shifted. The shifted pattern (now shown as pixel panel **38**.2) includes additional data D1 provided through the signal lines **38**.2. The shifting between patterns may also utilize a strobing or shuttering of the light source **32**.

[**0052**] In the second intermediate pattern of **FIG. 7**, D1 represents the left-most column of pixel elements in the pattern of DMD**38**.2. After another predetermined period of time, the pattern (now shown as pixel panel **38**.3) is shifted again. The twice-shifted pattern includes additional data D2 provided through the signal lines **38**.2. In the third intermediate pattern of **FIG. 7**, D2 now represents the left-most column of pixel elements in the pattern of the DMD**38**.3. Thus, the pattern moves across the pixel panel **38** in a direction **138**. It is noted that the pattern direction **138**, as it is being provided to the pixel panel **38** from the signal lines **50**, is moving opposite to the scanning direction **136**. In some embodiments, the pattern may be shifted in additional directions, such as perpendicular to the scanning direction **136**.

[**0053**] Referring now to **FIG. 8**, in some embodiments, the maskless photolithography system **30** performs two-dimensional digital scanning by rapidly moving the image relative to the subject **42** in one direction (in addition to the scanning motion) while the subject is positioned on the stage **44** to accommodate the other direction. The panel motor **55** moves the pixel panel **38** in one direction, represented by the y-arrow **134**. The scanning motor **55** scans the stage **44**, and hence the subject **42** in a direction **136**. Alternatively, the stage **44** can be fixed and the panel motor **55** can scan the pixel panel **38** (and the lenses **40**) opposite to direction **136**.

[**0054**] The image from the pixel panel **38** and/or the subject **42** is aligned at an angle θ with the scan direction **136**. Considering that each pixel projected onto subject **42** has a length of l and a width of w, then θ can be determined as:

$$\theta = \tan^{-1}\left(\frac{w - 1/M}{N \times l}\right) \tag{2}$$

[**0055**] In another embodiment, the offset may go in the opposite direction, so that θ can be determined as:

$$\theta = \tan^{-1}\left(\frac{w + 1/M}{N \times l}\right) \tag{3}$$

[**0056**] Referring to **FIGS. 9 and 10**.**1**, consider for example two sites **140**.**1**, **142**.**1** on the subject **42**. Initially, the two sites **140**.**1** and **142**.**1** are simultaneously exposed by pixel elements P**1** and P**50**, respectively, of the pixel panel **38**. The pixel elements P**1** and P**50** are located at a row RO and columns C**1** and C**0**, respectively, of the pixel panel **38**. This row and column designation is arbitrary, and has been identified in the present embodiment to clarify the example. The following discussion will focus primarily on site **140**.**1**. It is understood, however, that the methods discussed herein are typically applied to multiple sites of the subject, including the site **142**.**1**, but further illustrations and discussions with respect to site **142**.**1** will be avoided for the sake of clarity.

[**0057**] As can be clearly seen in **FIG. 9**, the pixel panel **38** is angled with respect to the subject **42** and the scan direction **136**. As the system **30** scans, pixel element P**11** would normally be projected directly on top of site **140**.**1**. However, as shown in **FIG. 10**.**2**, the pixel element P**11** exposes at a location **140**.**11** that is slightly offset in the y direction (or -y direction) from the site **140**.**1**. As the system **30** continues to scan, pixel elements P**12**-P**14** are exposed on offset locations **140**.**12**-**140**.**14**, respectively, shown in **FIGS. 10**.**3**-**10**.**5**, respectively. Pixel elements P**11**-P**14** are on adjacent consecutive rows R**1**, R**2**, R**3**, R**4** of column C**1** of the pixel panel **38**.

[**0058**] In the present embodiment, the scanning motor **52** moves the stage **44** (and hence the subject **42**) a distance of l, the length of the pixel site **140**.**1**, for each projection. To provide the offset discussed above, the panel motor **55** moves the pixel panel **38** an additional distance of l/(N−1) for each projection. (N=5 in the present example). Therefore, a total relative movement SCAN STEP for each projection is:

$$\text{SCAN STEP}=l+l/(N-1). \tag{4}$$

[**0059**] In another embodiment, the offset may go in the opposite direction, so that the total relative movement SCAN STEP for each projection is:

$$\text{SCAN STEP}=l-l/(N-1). \tag{5}$$

[**0060**] In some embodiments, the panel motor **55** is not needed. Instead, the scanning motor **52** moves the stage the appropriate length (equation 4 or 5, above).

[**0061**] Once N locations have been exposed, the next pixel elements being projected onto the desired locations are of an adjacent column. With reference to **FIG. 10**.**6**, in the present example, a pixel element P**2** at row R**5**, column C**2** exposes a location **140**.**2** that is slightly offset in the x direction (or -x direction, depending on whether equation 4 or 5 is used) from the site **140**.**1**. As the system **30** continues to scan, pixel elements P**21**-P**24** are exposed on offset locations **140**.**21**-**140**.**24**, respectively, shown in **FIGS. 10**.**7**-**10**.**10**, respectively. Pixel elements P**21**-P**24** are on adjacent consecutive rows R**6**, R**7**, R**8**, R**9** of column C**2** of the pixel panel **38**.

[**0062**] Once N more pixel locations have been exposed, the next pixel elements being projected onto the desired locations are of yet another adjacent column. With reference to **FIG. 10**.**11**, in the present example, a pixel element P**3** at row RIO, column C**3** exposes a location **140**.**3** that is slightly offset in the x direction (or -x direction, depending on whether equation 4 or 5 is used) from the location **140**.**2**. As the system **30** continues to scan, pixel elements P**31**-P**34** are exposed on offset locations **140**.**31**-**140**.**34**, respectively, shown in **FIGS. 10**.**12**-**10**.**15**, respectively. Pixel elements P**31**-P**34** are on adjacent consecutive rows R**11**, R**12**, R**13**, R**14** of column C**3** of the pixel panel **38**.

[**0063**] The above process repeats to fully scan the desired overlapped image. With reference to **FIG. 10**.**16**, in the present example, a pixel element P**4** at row R**15**, column C**4** exposes a location **140**.**4** that is slightly offset in the x direction (or -x direction, depending on whether equation 4 or 5 is used) from the location **140**.**3**. As the system **30** continues to scan, pixel elements P**41**-P**44** are exposed on offset locations **140**.**41**-**140**.**44**, respectively, shown in **FIGS. 10**.**17**-**10**.**20**, respectively. Pixel elements P**41**-P**44** are on adjacent consecutive rows R**16**, R**17**, R**18**, R**19** of column C**4** of the pixel panel **38**.

[**0064**] Point Array System and Method

[**0065**] Referring now to **FIG. 11**, in another embodiment of the present invention, the photolithography system **30** utilizes a unique optic system **150** in addition to the lens system **40**. The optic system **150** is discussed in detail in U.S. patent Ser. No. 09/480,796, which is hereby incorporated by reference. It is understood that the lens system **40** is adaptable to various components and requirements of the photolithography system **30**, and one of ordinary skill in the art can select and position lenses appropriately. For the sake of example, a group of lenses **40***a* and an additional lens **40***b* are configured with the optic system **150**.

[0066] The optic system **150** includes a grating **152** and a point array **154**. The grating **152** may be a conventional shadow mask device that is used to eliminate and/or reduce certain bandwidths of light and/or diffractions between individual pixels of the pixel panel **38**. The grating **152** may take on various forms, and in some embodiments, may be replaced with another device or not used at all.

[0067] The point array **154** is a multi-focus device. There are many types of point arrays, including a Fresnel ring, a magnetic e-beam lens, an x-ray controlled lens, and an ultrasonic controlled light condensation device for a solid transparent material.

[0068] In the present embodiment, the point array **154** is a compilation of individual microlenses, or microlens array. In the present embodiments, there are as many individual microlenses as there are pixel elements in the pixel panel **38**. For example, if the pixel panel **38** is a DMD with 600×800 pixels, then the microlens array **154** may have 600×800 microlenses. In other embodiments, the number of lenses may be different from the number of pixel elements in the pixel panel **38**. In these embodiments, a single microlens may accommodate multiple pixels elements of the DMD, or the pixel elements can be modified to account for alignment. For the sake of simplicity, only one row of four individual lenses **154***a*, **154***b*, **154***c*, **154***d* will be illustrated. In the present embodiment, each of the individual lenses **154***a*, **154***b*, **154***c*, **154***d* is in the shape of a rain drop. It is understood, however, that shapes other than those illustrated may also be used.

[0069] Similar to the lens system **40** of **FIG. 2**, the optic system **150** is placed between the pixel panel **38** and the subject **42**. For the sake of example, in the present embodiment, if the pixel panel **38** is a DMD device, light will (selectively) reflect from the DMD device and towards the optic system **150**. If the pixel panel **38** is a liquid crystal display ("LCD") device or a transparent spatial light modulator ("SLM"), light will (selectively) flow through the LCD device and towards the optic system **150**. To further exemplify the present embodiment, the pixel panel **38** includes one row of elements (either mirrors or liquid crystals) for generating four pixel elements.

[0070] In continuance with the example, four different pixel elements **156***a*, **156***b*, **156***c*, **156***d* are projected from each of the pixels of the pixel panel **38**. In actuality, the pixel elements **156***a*, **156***b*, **156***c*, **156***d* are light beams that may be either ON or OFF at any particular instant (meaning the light beams exist or not, according to the pixel-mask pattern), but for the sake of discussion all the light beams are illustrated.

[0071] The pixel elements **156***a*, **156***b*, **156***c*, **156***d* pass through the lens system **40***a* and are manipulated as required by the current operating conditions. As discussed earlier, the use of the lens system **40***a* and **40***b* are design options that are well understood in the art, and one or both may not exist in some embodiments. The pixel elements **156***a*, **156***b*, **156***c*, **156***d* that are manipulated by the lens system **40***a* are designated **158***a*, **158***b*, **158***c*, **158***d*, respectively.

[0072] The pixel elements **158***a*, **158***b*, **158***c*, **158***d* then pass through the microlens array **154**, with each beam being directed to a specific microlens **154***a*, **154***b*, **154***c*, **154***d*, respectively. The pixel elements **158***a*, **158***b*, **158***c*, **158***d* that are manipulated by the microlens array **154** are designated as individually focused light beams **160***a*, **160***b*, **160***c*, **160***d*, respectively. As illustrated in **FIG. 11**, each of the light beams **160***a*, **160***b*, **160***c*, **160***d* are being focused to focal points **162***a*, **162***b*, **162***c*, **162***d* for each pixel element. That is, each pixel element from the pixel panel **38** is manipulated until it focuses to a specific focal point. It is desired that the focal points **162***a*, **162***b*, **162***c*, **162***d* exist on the subject **42**. To achieve this goal, the lens **40***b* may be used in some embodiments to refocus the beams **160***a*, **160***b*, **160***c*, **160***d* on the subject **42**. **FIG. 11** illustrates focal points **162***a*, **162***b*, **162***c*, **162***d* as singular rays, it being understood that the rays may not indeed be focused (with the possibility of intermediate focal points, not shown) until they reach the subject **42**.

[0073] Continuing with the present example, the subject **42** includes four exposure sites **170***a*, **170***b*, **170***c*, **170***d*. The sites **170***a*, **170***b*, **170***c*, **170***d* are directly associated with the light beams **162***a*, **162***b*, **162***c*, **162***d*, respectively, from the microlenses **154***a*, **154***b*, **154***c*, **154***d*, respectively. Also, each of the sites **170***a*, **170***b*, **170***c*, **170***d* are exposed simultaneously. However, the entirety of each site **170***a*, **170***b*, **170***c*, **170***d* is not exposed at the same time.

[0074] Referring now to **FIG. 12**, the maskless photolithography system **30** with the optic system **150** can also performs two-dimensional digital scanning, as discussed above with reference to **FIG. 8**. For example, the image from the pixel panel **38** may be aligned at the angle θ (equations 2 and 3, above) with the scan direction **136**.

[0075] Referring also to FIGS. **13**, the present embodiment works very similar to the embodiments of FIGS. **9-10**. However, instead of a relatively large location being exposed, the pixel elements are focused and exposed to a relatively small point (e.g., individually focused light beams **162***a*, **162***b*, **162***c*, **162***d* from **FIG. 11**) on the sites **170***a*, **170***b*, **170***c*, **170***d*.

[0076] First of all, the pixel element **156***a* exposes the individually focused light beam **162***a* onto the single site **170***a* of the subject **42**. The focused light beam **162***a* produces an exposed (or unexposed, depending on whether the pixel element **156***a* is ON or OFF) focal point PT1. As the system **30** scans, pixel element **156***b* exposes the individually focused light beam **162***b* onto the site **170***a*. The focused light beam **162***b* produces an exposed (or unexposed) focal point PT2. Focal point PT2 is slightly offset from the focal point PT1 in the y direction (or -y direction). As the system **30** continues to scan, pixel elements **156***c* and **156***d* expose the individually focused light beams **162***c* and **162***d*, respectively, onto the site **170***a*. The focused light beams **162***c* and **162***d* produce exposed (or unexposed) focal points PT3 and PT4, respectively. Focal point PT3 is slightly offset from the focal point PT2 in the y direction (or -y direction), and focal point PT4 is similarly offset from the focal point PT3.

[0077] Once N pixel elements have been projected, the next pixels being projected onto the desired sites are of an adjacent column. This operation is similar to that shown in **FIGS. 10.6-10.20**. The above process repeats to fully scan the desired overlapped image on the site **170***a*.

[0078] It is understood that while light beam **162***a* is being exposed on the site **170***a*, light beam **162***b* is being exposed on the site **170***b*, light beam **162***c* is being exposed on the site **170***c*, and light beam **162***d* is being exposed on the site **170***d*. Once the system **30** scans one time, light beam **162***a* is exposed onto a new site (not shown), while light beam **162***b* is exposed on the site **170***a*, light beam **162***c* is exposed on the site **170***b*, and light beam **162***d* is exposed on the site **170***c*. This repeats so that the entire subject can be scanned (in the y direction) by the pixel panel **38**.

[**0079**] It is further understood that in some embodiments, the substrate **42** may be moved rapidly while the light beams (e.g., **162***a-d*) transition from one site to the other (e.g., **170***a*-**170***d*, respectively), and slowly while the light beams are exposing their corresponding sites.

[**0080**] By grouping several pixel panels together in the x-direction, the entire subject can be scanned by the pixel panels. The computer system **36** can keep track of all the data provided to each pixel panel to accommodate the entire scanning procedure. In other embodiments, a combination of scanning and stepping can be performed. For example, if the subject **42** is a wafer, a single die (or group of die) can be scanned, and then the entire system **30** can step to the next die (or next group).

[**0081**] The example of FIGS. **11**-**13** are limited in the number of pixel elements for the sake of clarity. In the figures, each focal point has a diameter of about ½ the length l or width w of the site **170***a*. Since N=4 in this example, the overlap spacing is relatively large and the focal points do not overlap very much, if at all. As the number of pixel elements increase (and thus N increases), the resolution and amount of overlapping increase, accordingly.

[**0082**] For further example, **FIG. 14** illustrates a site **220** that has been exposed by 600 pixel elements with focal points PT1-PT**600** (e.g., from a 600×800 DMD). As can be seen, the focal points PT1-PT**600** are arranged in an array (similar to equation 1, above) of:

$$(M,N)=20 \text{ focal points} \times 30 \text{ focal points}. \tag{6}$$

[**0083**] By selectively turning ON and OFF the corresponding pixel elements, a plurality of structures **222, 224, 226** can be formed on the site **220**. It is noted that structures **222**-**226** have good resolution and can be drawn to various different shapes, including diagonal. It is further noted that many of the focal points on the periphery of the site **220** will eventually overlap with focal points on adjacent sites. As such, the entire subject **42** can be covered by these sites.

[**0084**] Alternatively, certain focal points or other types of exposed sites can be overlapped to provide sufficient redundancy in the pixel panel **38**. For example, the same **600** focal points of **FIG. 14** can be used to produce an array of:

$$(M,N)=20 \text{ focal points} \times 15 \text{ focal points}. \tag{7}$$

[**0085**] By duplicating the exposure of each focal point, this redundancy can accommodate one or more failing pixel elements in the pixel panel **38**.

[**0086**] Additional Embodiments of the Point Array System

[**0087**] FIGS. **15**-**27**, below, describe additional configurations of the point array system that can be implemented, each providing different advantages. To the extent that similar components are used as those listed in **FIGS. 2 and 11**, the same reference numerals will also be used.

[**0088**] Referring now to **FIG. 15, a** maskless photolithography system **300** is similar to the systems of **FIGS. 2 and 11**. The system **300** includes a transparent spatial light modulator ("SLM") as the pixel panel **38**. The light **48** passes through the SLM **38** and, according to the pixel pattern provided to the SLM, is selectively transmitted towards the substrate **42**.

[**0089**] Referring now to **FIG. 16, a** maskless photolithography system **320** is similar to the system **300** of **FIG. 15**, except that it positions the micro-lens array **154** and the grating **152** before (as determined by the flow of light **48**) the SLM **38**.

[**0090**] Referring now to **FIG. 17, a** maskless photolithography system **340** is similar to the system **320** of **FIG. 16**, except that it uses an optical diffraction element **342** instead of the micro-lens array **154** and grating **152**. The optical diffraction element **342** may be of the type used for holograms, or a binary diffraction component.

[**0091**] Referring now to **FIG. 18, a** maskless photolithography system **360** is similar to the system **320** of **FIG. 16**, except that the SLM **38** is non-transparent. For this system **360**, a beam splitter **362** is used to direct the incoming light **48** towards the SLM **38**, and the reflected image towards the lens system **40***a*.

[**0092**] Referring now to **FIG. 19, a** maskless photolithography system **380** is similar to the system **360** of **FIG. 18**, except for the location of the components. The incoming light **48** first passes through the microlens array **154**, the grating **152**, and then through the beam splitter **362**. At this time, the light is separately focusable into individual pixels. The pixelized light then reflects off the SLM **38** and the resulting image passes back through the beam splitter **362** and onto the subject **42**.

[**0093**] Referring now to **FIG. 20, a** maskless photolithography system **400** is similar to the system **380** of **FIG. 19**, except that the beam splitter **382** is positioned adjacent to the SLM **38**.

[**0094**] Referring now to **FIG. 21, a** maskless photolithography system **420** is similar to the system **400** of **FIG. 20**, except that instead of a microlens array and grating, the system uses the optical diffraction component **342**.

[**0095**] Referring now to **FIG. 22, a** maskless photolithography system **440** is similar to the system **400** of **FIG. 20**, except that the image lens **40***b* is positioned on both sides of the beam splitter **382**.

[**0096**] Referring now to **FIG. 23, a** maskless photolithography system **460** is similar to the system **420** of **FIG. 21**, except that the image lens **40***b* is positioned on both sides of the beam splitter **382**.

[**0097**] Referring now to **FIG. 24, a** maskless photolithography system **480** is similar to the system **320** of **FIG. 16**, except that the pixel panel **38** is a DMD, and the light reflects off the individual micro mirrors of the DMD at a predetermined angle.

[**0098**] Referring now to **FIG. 25, a** maskless photolithography system **500** is similar to the system **340** of **FIG. 17**, except that the pixel panel **38** is a DMD, and the light reflects off the individual micro mirrors of the DMD at a predetermined angle.

[**0099**] Laser Diode Array

[**0100**] Referring now to **FIG. 26**, in another embodiment, a photolithography system **600** is similar to that in **FIGS. 2 and 11**, except that it uses light emitting diodes ("LEDs") or a laser diode array **610** (described later in greater detail) in place of the light source **32** and the pixel panel **38**. The laser diode array **610** includes multiple laser diodes **612** embedded within or mounted upon a substrate **614**, and is connected to the computer aided design system **36** through a connector **616**. The connector **616** enables the design system **36** to control the laser diode array **610** through the signal line(s) **50**. A cooler **618** is operable to prevent excessive heat buildup on the substrate **614**.

[**0101**] For purposes of clarity, the operation of a single laser diode **612** from the laser diode array **610** will be discussed. The laser diode **612** projects a laser beam **620**, which may be of varying wavelengths and intensity. The wavelength and intensity of the beam **620** may be altered to achieve a desired result. For example, the intensity and/or wavelength of the beam **620** may be altered by regulating the current supplied to the laser diode **612**. Such regulation may be exercised on an individual diode basis or multiple laser diodes **612** may be controlled at once.

[**0102**] The shape of the beam **620** projected by the laser diode **612** may be distorted relative to some desired beam shape, and so may require correction. Therefore, the beam **620** may be passed through an aspherical or cylindrical lens array **622** to reshape the beam into the desired shape. For example, the laser diode **612** may produce a beam **620** having an oval shape, instead of a desired circular shape. Therefore, the lens array **622** may be utilized to reshape the oval beam into a circular beam. Once the laser beam **620** is reshaped, it passes through the lens system **40***a* and then the micro-lens array **154**. As described in reference to **FIG. 11**, the micro-lens array **154** may be a point array, which is a multi-focus device. The beam **620** then passes through the grating **152**, which may, as in **FIG. 11**, take on various forms, be placed in alternate locations, and in some embodiments, may be replaced with another device or not used at all. The beam **620** then passes through a second set of lenses **40***b* before exposing a discrete site on the substrate **42**.

[**0103**] Referring now to **FIG. 27**, an exemplary laser diode array **610** is illustrated. The laser diode array **610** is embedded in or connectable to a substrate **614**, which includes embedded circuitry **624**. The circuitry **624**, which may include embedded microelectronics and electrical connectors, is operable to provide parallel and/or serial control signals and/or address lines to the laser diode array **610**. These control signals may enable the regulation of the wavelength and/or intensity of the laser beam **620**, among other things. Connectable to the substrate **614** is a connector **616**, which enables the computer aided design system **36** to control the laser diode array **610** through the signal line(s) **50** and the circuitry **624**. Proximate to the substrate **614** is a cooler **618**, which may be a thermoelectric cooler such as a Peltier cooler. The cooler **618** permits uniform cooling to stabilize the performance of the laser diode array **610**. The laser diode array **610** may also include memory (not shown), either embedded into the substrate or made accessible to the array **610** using other common techniques.

[**0104**] Referring now to **FIG. 28, a** macrostructure embodiment of the exemplary laser diode array **610** of **FIG. 27** is illustrated. The substrate **614** serves as a base for multiple braces **626**, which are connected to the substrate **614** and which may be spaced at the millimeter level. For example, the braces **626** may be spaced so that they are separated by one millimeter, although the actual spacing may depend on such factors as the desired functionality of the laser diode array **610** and the construction techniques utilized. In the current embodiment, each brace **626** may serve as a support for one of the laser diodes **612**, although in other embodiments each brace **626** may support multiple laser diodes **612**. Each laser diode **612** is fastened to one of the braces **626** by wire bonds **628**, although other fastening means may be used. A portion of the circuitry **624** is connected to each diode, either directly or indirectly, such as through the braces **626** and the wire bonds **628**.

[**0105**] Referring now to **FIG. 29, a** microstructure embodiment of the exemplary laser diode array **610** of **FIG. 27** is illustrated, such as a commercially available vertical cavity surface emitting laser ("VCSEL") diode array. The individual laser diodes **612** may be integrated into the substrate **614** in the VCSEL diode array and may be spaced at the micrometer level. For example, the laser diodes **612** are commonly spaced from one to ten micrometers apart, although greater or lesser distances may be appropriate depending on the particular functionality desired. Similarly to the macrostructure of **FIG. 28**, the laser diodes may be connected to a portion of the circuitry **624**.

[**0106**] Referring now to **FIG. 30**, in an alternative embodiment, a maskless photolithography system **640** is similar to the system **600** of **FIG. 26**, except that the laser diode array **610** serves as a light source for a pixel panel **38**, such as the pixel panel **38** of **FIG. 2**.

[**0107**] Referring now to **FIG. 31, a** maskless photolithography system **660** is similar to the system **600** of **FIG. 26**, except that the laser diode array **610** replaces the grate **152** and/or the micro-lens array **154**.

[**0108**] Referring now to **FIG. 32, a** maskless photolithography system **680** is similar to the system **600** of **FIG. 26**, except that the laser diode array **610** projects the laser beam **620** directly onto the substrate **42**. In alternative embodiments, the laser diode array **610** may project the laser beam **620** onto a variety of subjects. For example, the laser diode array **610** may be used as a head for a thermal printer, enabling the printer to write directly to a thermally sensitive subject.

[**0109**] Referring now to **FIG. 33**, in another alternative embodiment, the laser diode array **610** is utilized as a high power light source **700** by combining the output of multiple laser diodes **612**. The laser diodes **612** of the array **610**, of which only ten are illustrated for the sake of clarity, project laser beams **620**. The beams **620** first pass through the lens array **622** for any desired reshaping of the beams **620** as described above in reference to **FIG. 26**. The beams **620** then pass through the micro-lens array **702**. The micro-lens array **702** provides enhanced coupling between the laser diodes **612** and multiple multimode optic fibers **704**. The fibers **704** may be bundled into one or more outputs, which may transfer the light to optics for beam reshaping, decorrelation, and/or the application of other techniques. The output may be used for photolithography, as a laser pump for other lasing media, or in a variety of other applications where such a high power light source may be desired. The present embodiment is shown utilizing the macrostructure of **FIG. 28**, although other laser diode arrays may be used to implement the high power light source.

[**0110**] One advantage of the laser diode array **610** is that it may be used to replace one or more DMDs or direct projection methods in photolithography. Another advantage is that using the laser diode array may reduce the loss of intensity previously experienced from the light source **32** and reflection imperfections in the pixel panel **38**. Additionally, the laser diode array may be focused on a very small point, thereby improving lithography performance.

[**0111**] In yet another embodiment, an array may be fabricated with three primary-color LEDs or laser diodes. The resulting color array may then be used as a projector for holography. In still another embodiment, the LED or laser diode array may be designed so that the array includes a series of incremental wavelengths. The resulting array may then be utilized for spectral analysis. In another embodiment, the array may serve as a lesion-mapping system.

[**0112**] While the invention has been particularly shown and described with reference to the preferred embodiment thereof, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention. For example, it is within the scope of the present invention that alternate types and/or arrangements of lasers may be used. Furthermore, the order of components such as the lenses **40***a*, **40***b*, the micro-lens array **154**, and/or the grating **152** may be altered in ways apparent to those skilled in the art. Additionally, the type and number of components may be supplemented, reduced or otherwise altered. For example, in another embodiment, the laser diode array **610** may be combined with the aspherical lens array **622** to form a single component. Therefore, the claims should be interpreted in a broad manner, consistent with the present invention.

What is claimed is:

1. A system for performing digital lithography onto a subject, the system comprising:

a laser diode array for generating a digital pattern, the array including a plurality of laser diodes operable to project at least one laser beam; and

a lens system for directing the digital pattern to the subject.

2. The system of claim 1 wherein the laser diode array is combined with the lens system to form a single unit.

3. The system of claim 1 further including a pixel panel, wherein the laser diode array serves as a light source for the pixel panel.

4. The system of claim 1 further including a lens array for reshaping the at least one beam.

5. The system of claim 4, wherein the laser diode array is combined with the lens array to form a single unit.

6. The system of claim 1 wherein the laser diodes are vertical cavity surface emitting lasers.

7. A method for performing digital lithography onto a subject, the method comprising:

generating a digital pattern using a laser diode array, the array including a plurality of laser diodes operable to project at least one laser beam;

projecting the digital pattern using the at least one beam; and

directing the projected digital pattern to the subject using a lens system.

8. The method of claim 7 further including reshaping the beam using a lens array.

9. A system for projecting a digital pattern onto a subject, the system comprising:

a laser diode array for generating a digital pattern, the array including a plurality of laser diodes; and

a lens system for directing the digital pattern to the subject.

10. The system of claim 9 wherein at least a portion of the subject is thermally sensitive.

11. The system of claim 9 wherein the laser diode array is a color array.

12. The system of claim 11 wherein the color array serves as a holographic projector.

13. The system of claim 9 wherein the system is a lesion-mapping system.

14. The system of claim 9 wherein the subject is a plurality of optical fibers, so that the system is operable as a high power light source.

15. A method for projecting a digital pattern onto a subject, the method comprising:

generating a digital pattern using a laser diode array, the array including a plurality of laser diodes operable to project at least one laser beam;

projecting the digital pattern using the at least one beam; and

directing the projected digital pattern to the subject using a lens system.

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