US007505206B2

(12) **United States Patent**
Deng et al.

(10) **Patent No.: US 7,505,206 B2**
(45) **Date of Patent: Mar. 17, 2009**

(54) **MICROLENS STRUCTURE FOR IMPROVED CMOS IMAGE SENSOR SENSITIVITY**

(75) Inventors: **Jack Deng**, Miaoli County (TW); **Chih-Kung Chang**, Hsin-Chu (TW); **Chin Chen Kuo**, Taipei (TW); **Ming-Chang Kao**, Taipei County (TW); **Fu-Tien Weng**, Hsinchu County (TW); **Bii-Junq Chang**, Hsin-Chu (TW)

(73) Assignee: **Taiwan Semiconductor Manufacturing Company**, Hsin-Chu (TW)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 99 days.

(21) Appl. No.: **11/456,249**

(22) Filed: **Jul. 10, 2006**

(65) **Prior Publication Data**

US 2008/0007839 A1 Jan. 10, 2008

(51) **Int. Cl.**
G02B 27/10 (2006.01)

(52) **U.S. Cl.** **359/619**; 359/626

(58) **Field of Classification Search** 359/618–620, 359/626; 348/207, 273–275
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,550,626 A 8/1996 Kobayashi et al.
7,068,432 B2 * 6/2006 Boettiger et al. 359/619

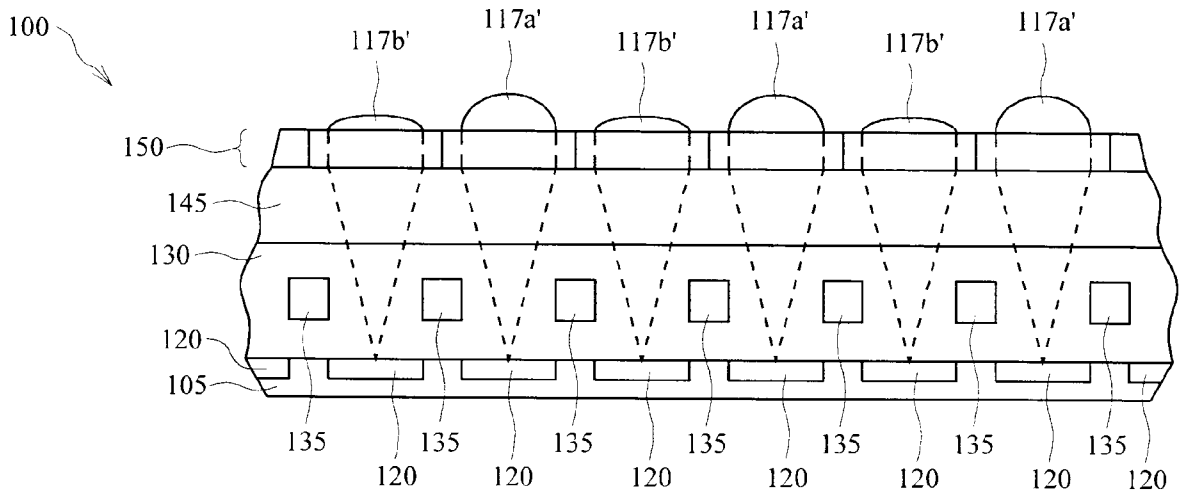
* cited by examiner

Primary Examiner—William C Choi
(74) *Attorney, Agent, or Firm*—Haynes and Boone, LLP

(57) **ABSTRACT**

A method of manufacturing a microlens device by depositing a microlens material layer over a substrate that includes photo-sensors. The microlens material layer is then exposed and developed to define microlens material elements, including first microlens material elements and second microlens material elements. Each second microlens material element is substantially greater in thickness relative to each first microlens material element. The microlens material elements are then heated to form a microlens array that includes first microlens array elements, each corresponding to a first microlens material element, and second microlens array elements, each corresponding to a second microlens material element. Each first microlens array element has a substantially greater focal length relative to each second microlens array element. For example, each second microlens array element is substantially greater in thickness relative to each first microlens array element.

10 Claims, 13 Drawing Sheets



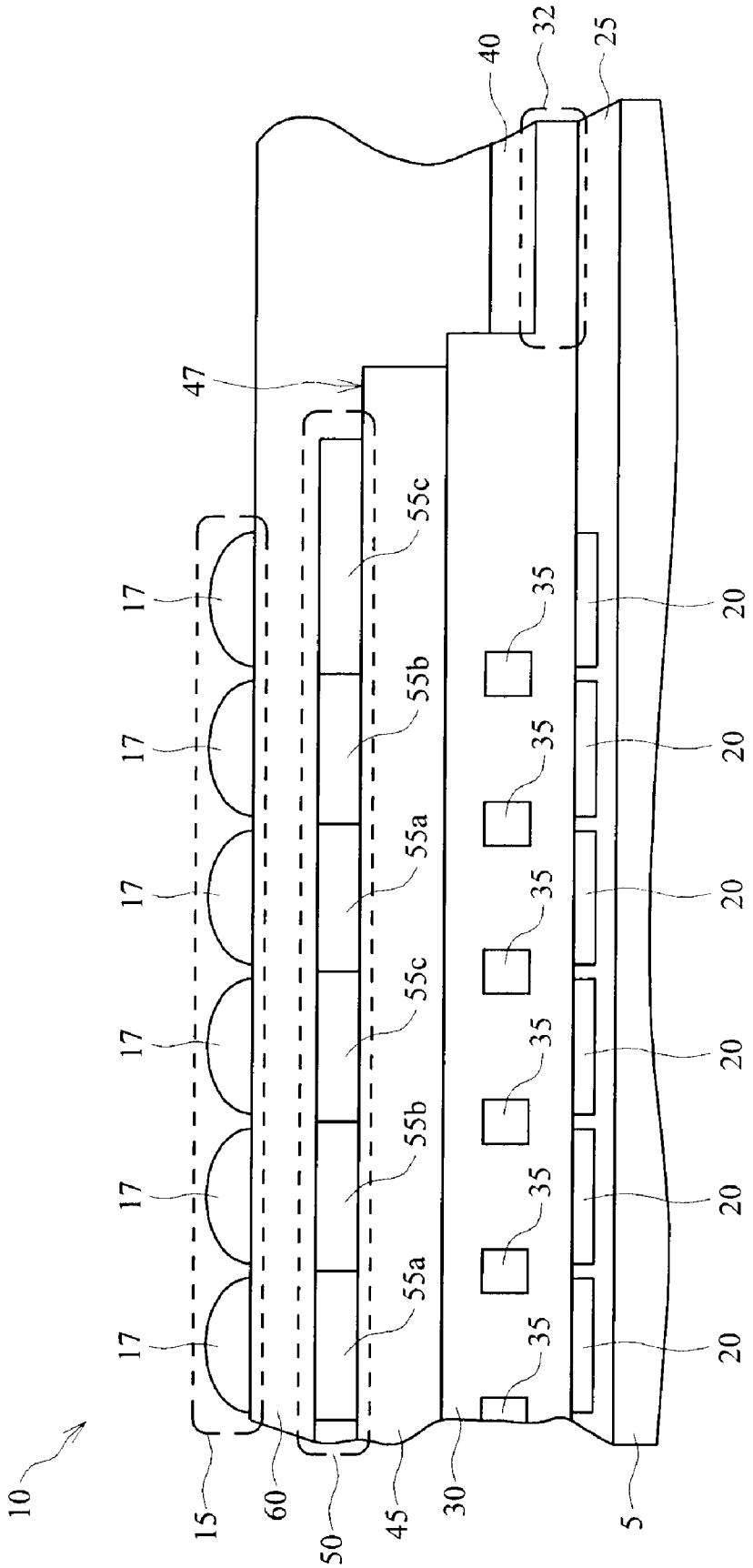


Fig. 1
(Prior Art)

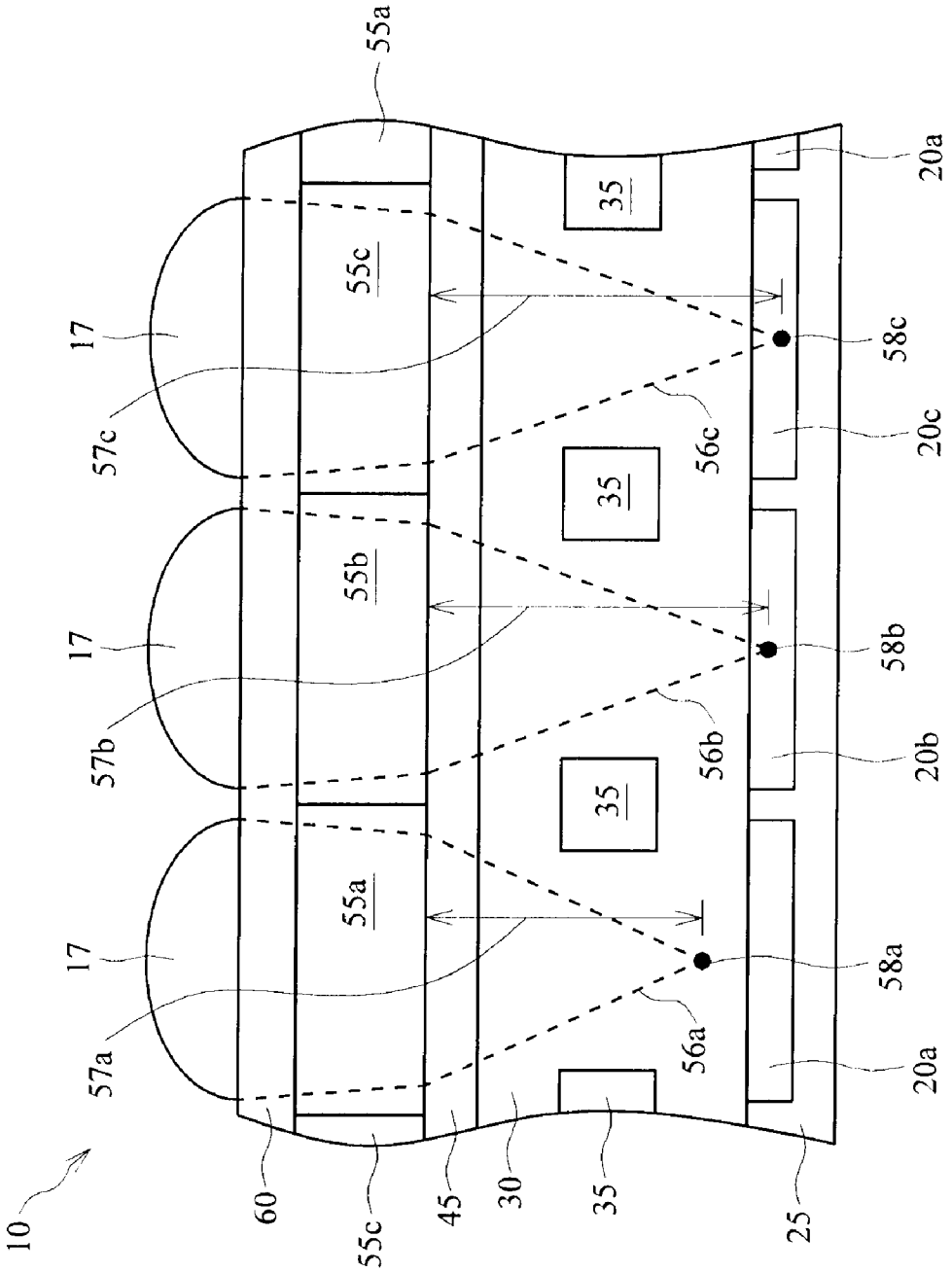


Fig. 2
(Prior Art)

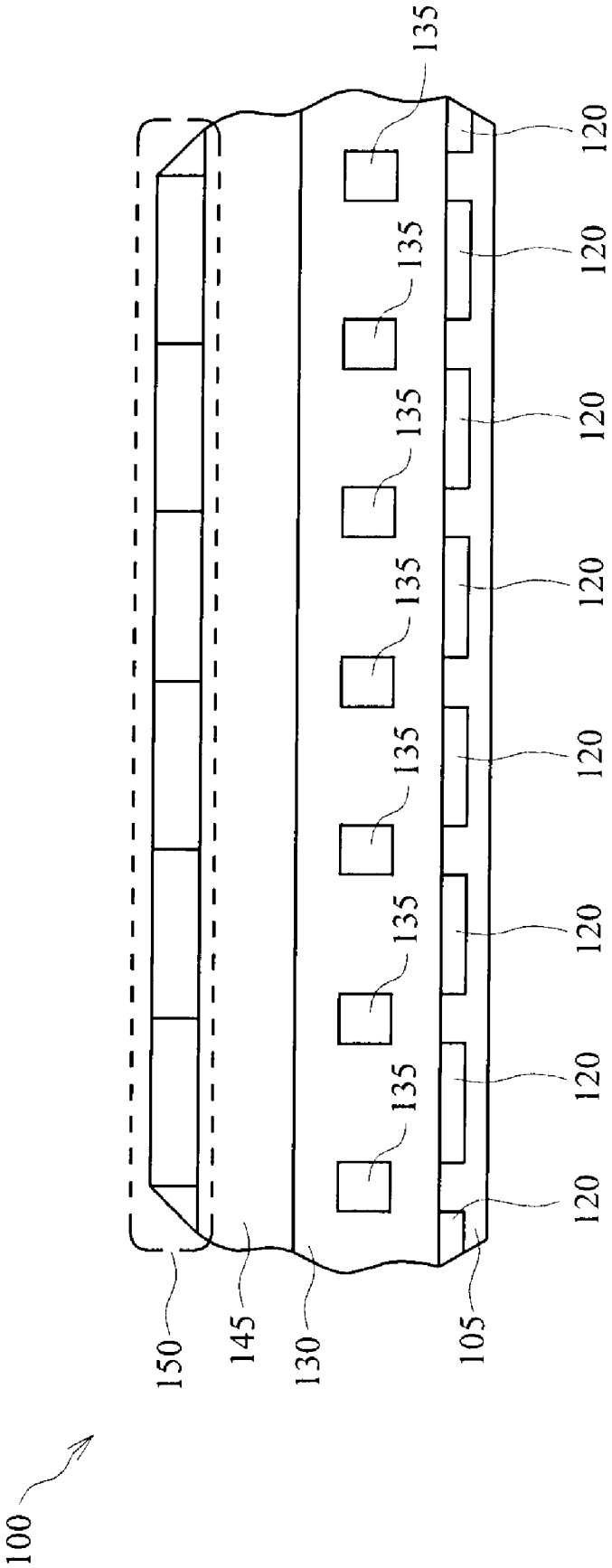


Fig. 3

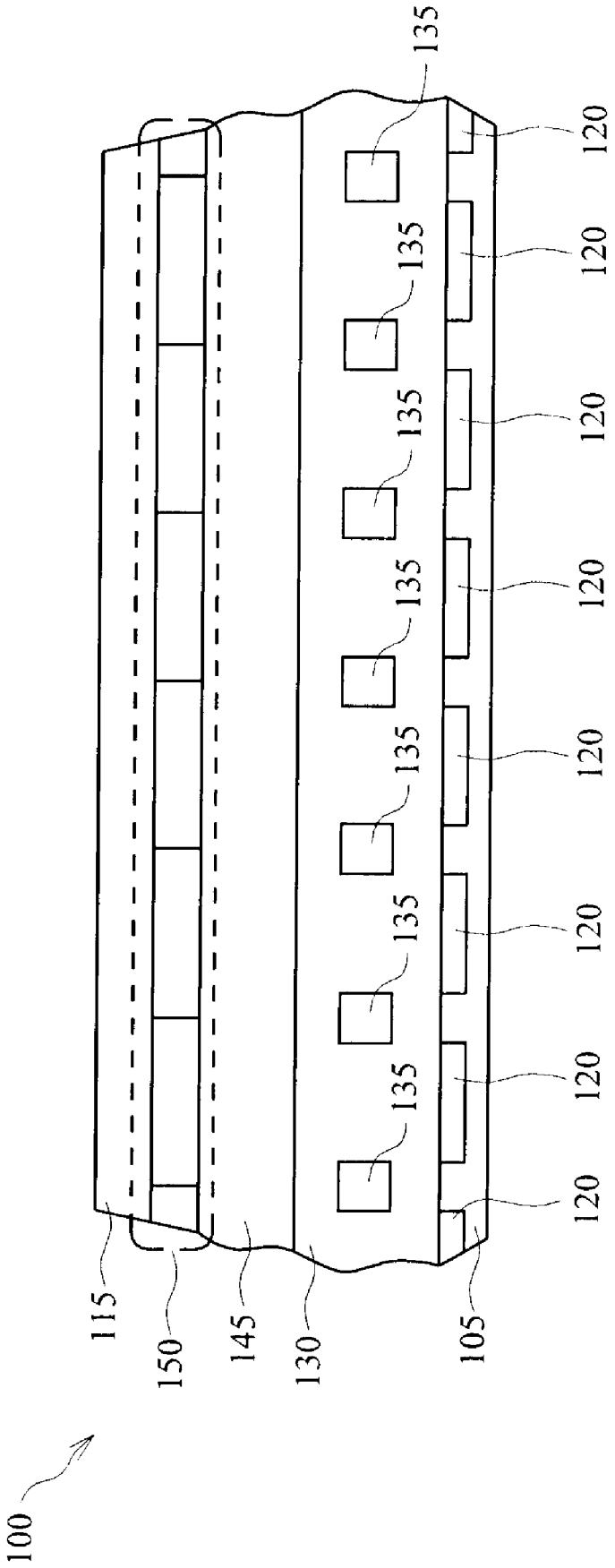


Fig. 4

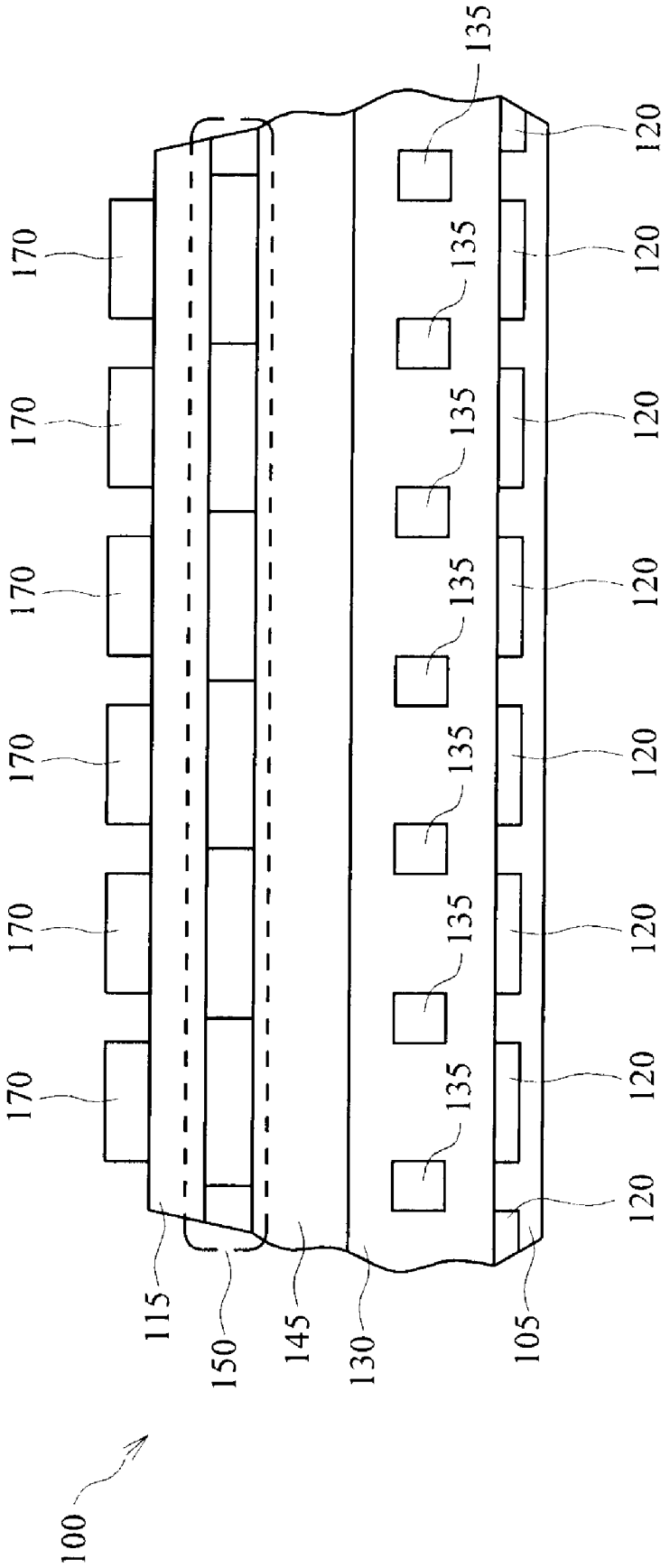

170
170
170
170
170
170
115
150
145
130
105
100
135
135
135
135
135
135
135
120
120
120
120
120
120
120
120

Fig. 5

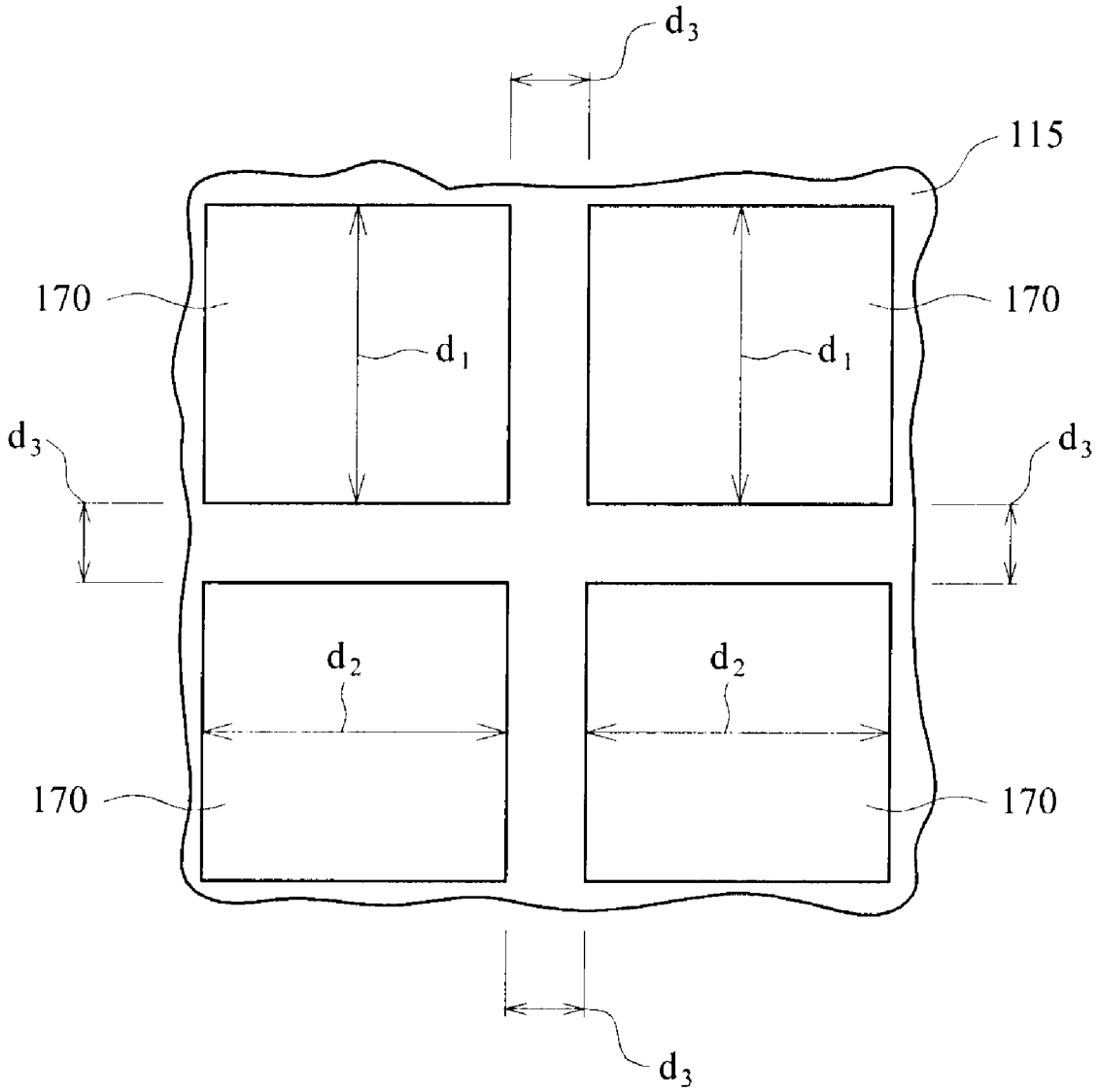


Fig. 6

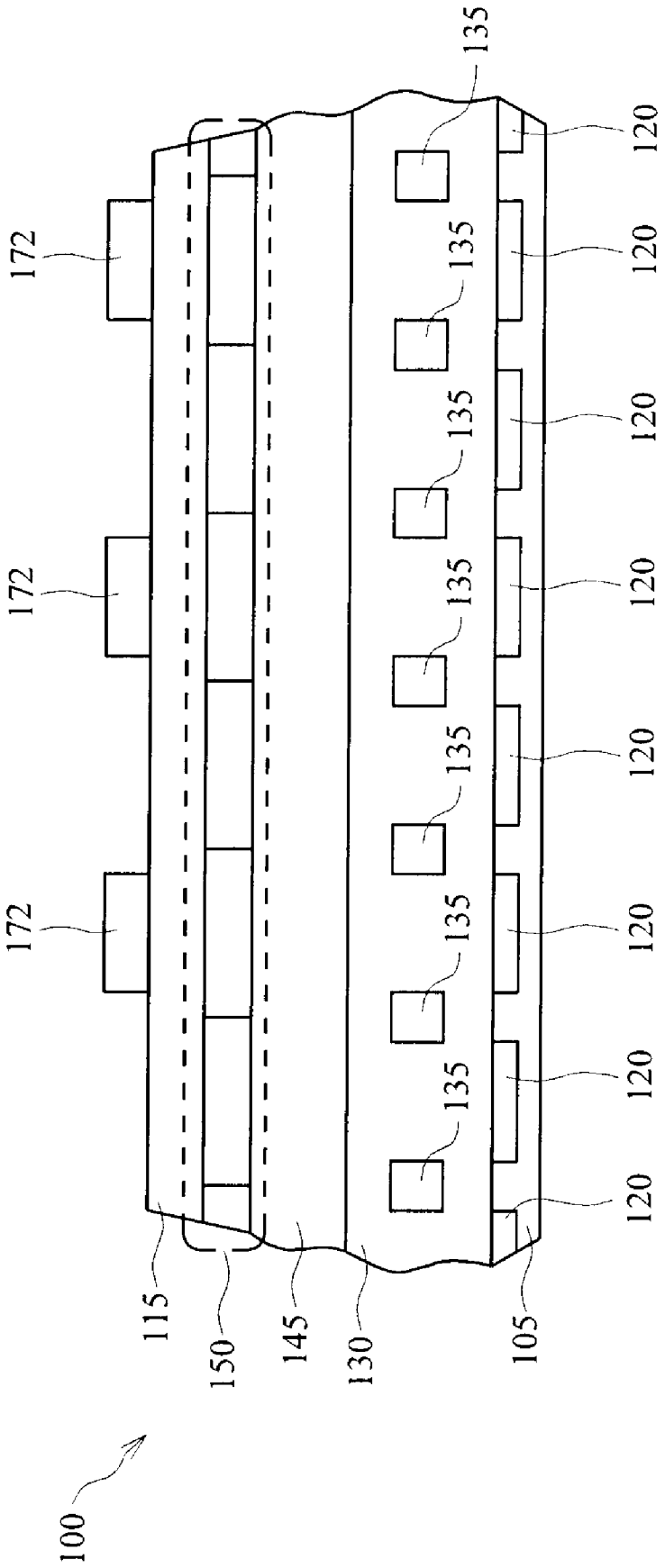

100
115
150
145
130
105
172
172
172
135
135
135
135
135
135
135
120
120
120
120
120
120
120
120

Fig. 7

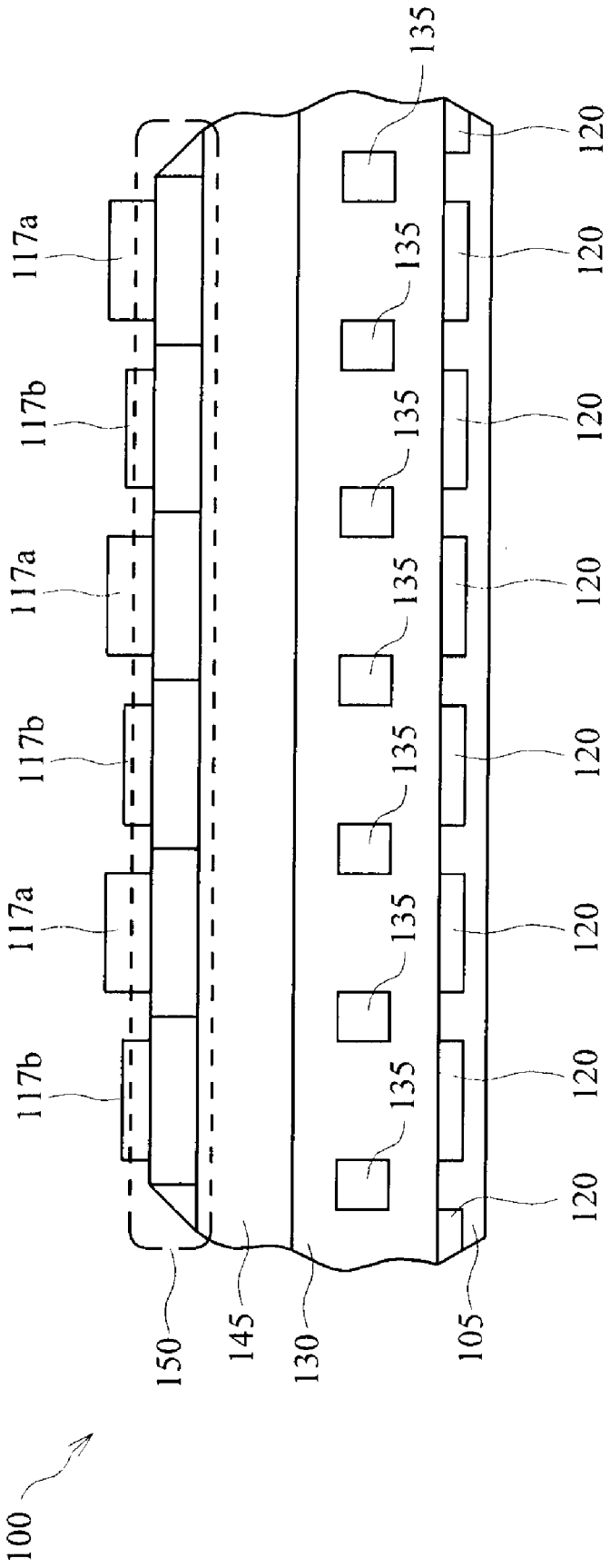

100
150
145
130
105
117b
117a
117b
117a
117b
117a
117b
135
135
135
135
135
135
135
120
120
120
120
120
120
120

Fig. 8

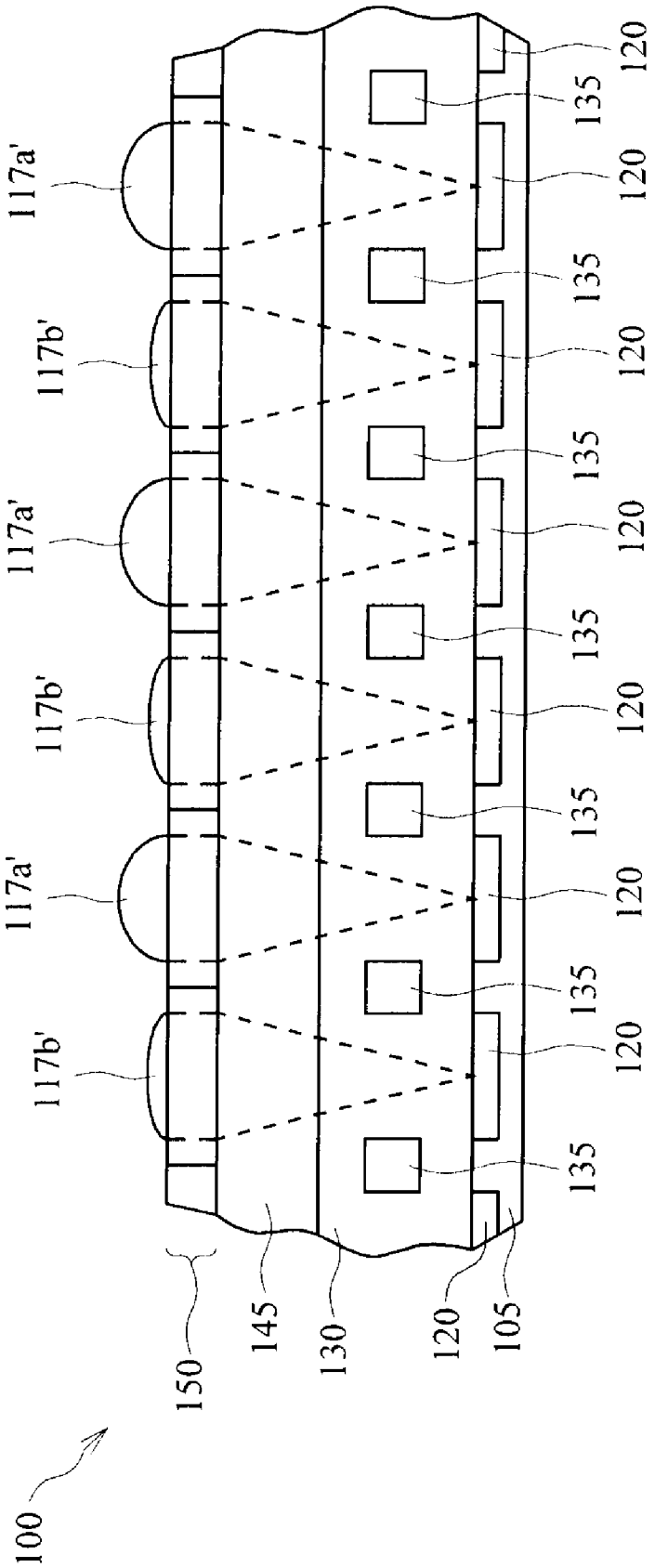

100
150
145
130
120
105
117b'
117a'
117b'
117a'
117b'
117a'
117b'
135
120

Fig. 9

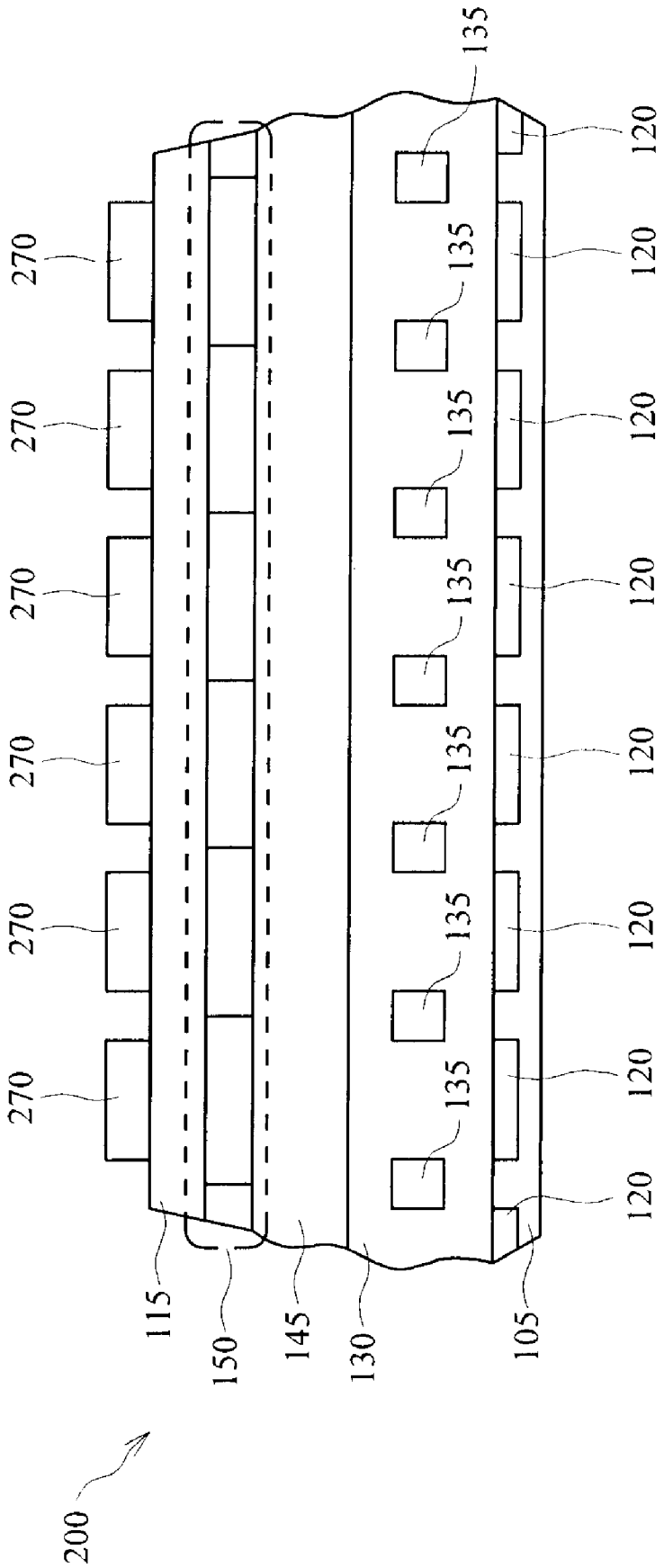

270
270
270
270
270
270
135
135
135
135
135
135
120
120
120
120
120
120
120
115
150
145
130
105
200

Fig. 10

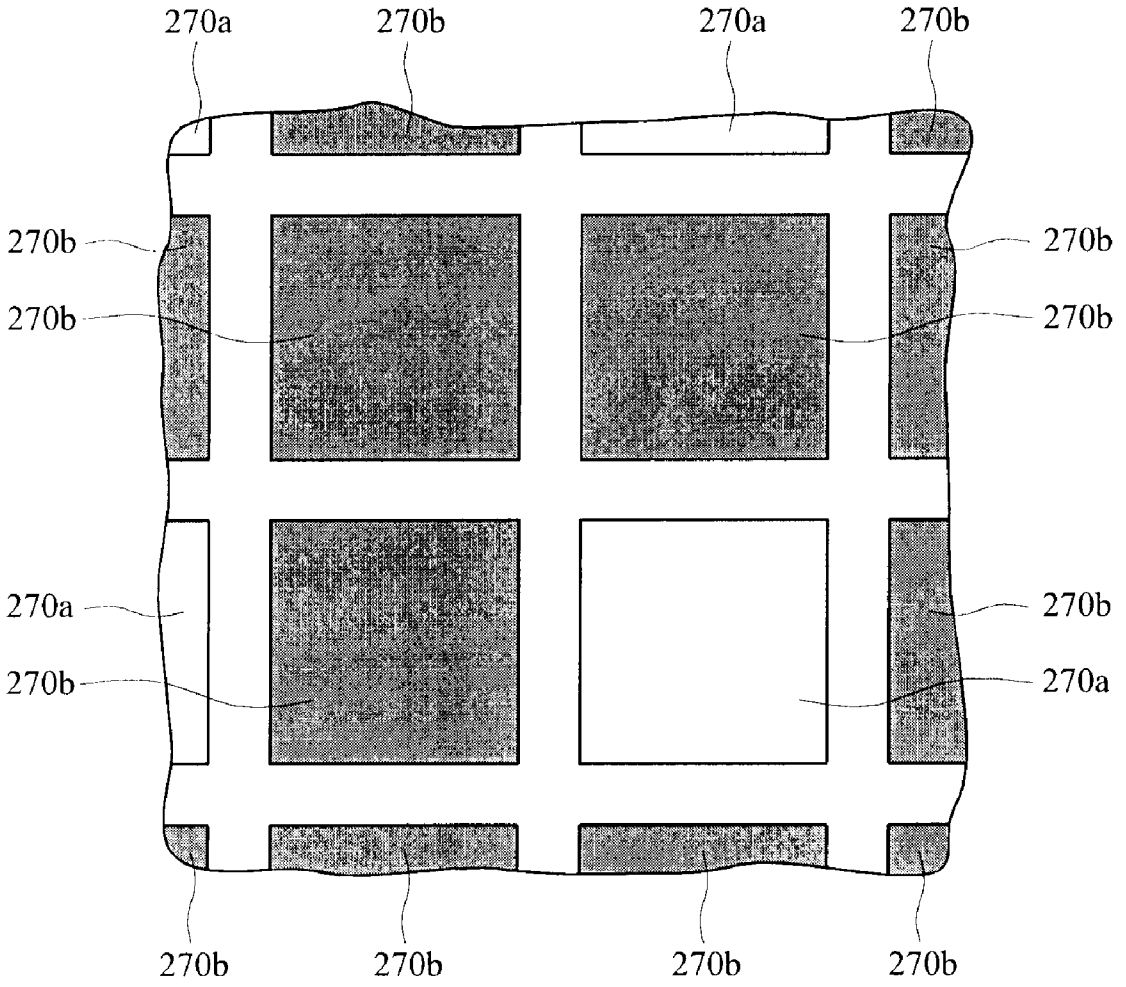

270a
270b
270a
270b
270b
270b
270b
270b
270a
270b
270b
270a
270b
270b
270b
270b

Fig. 11

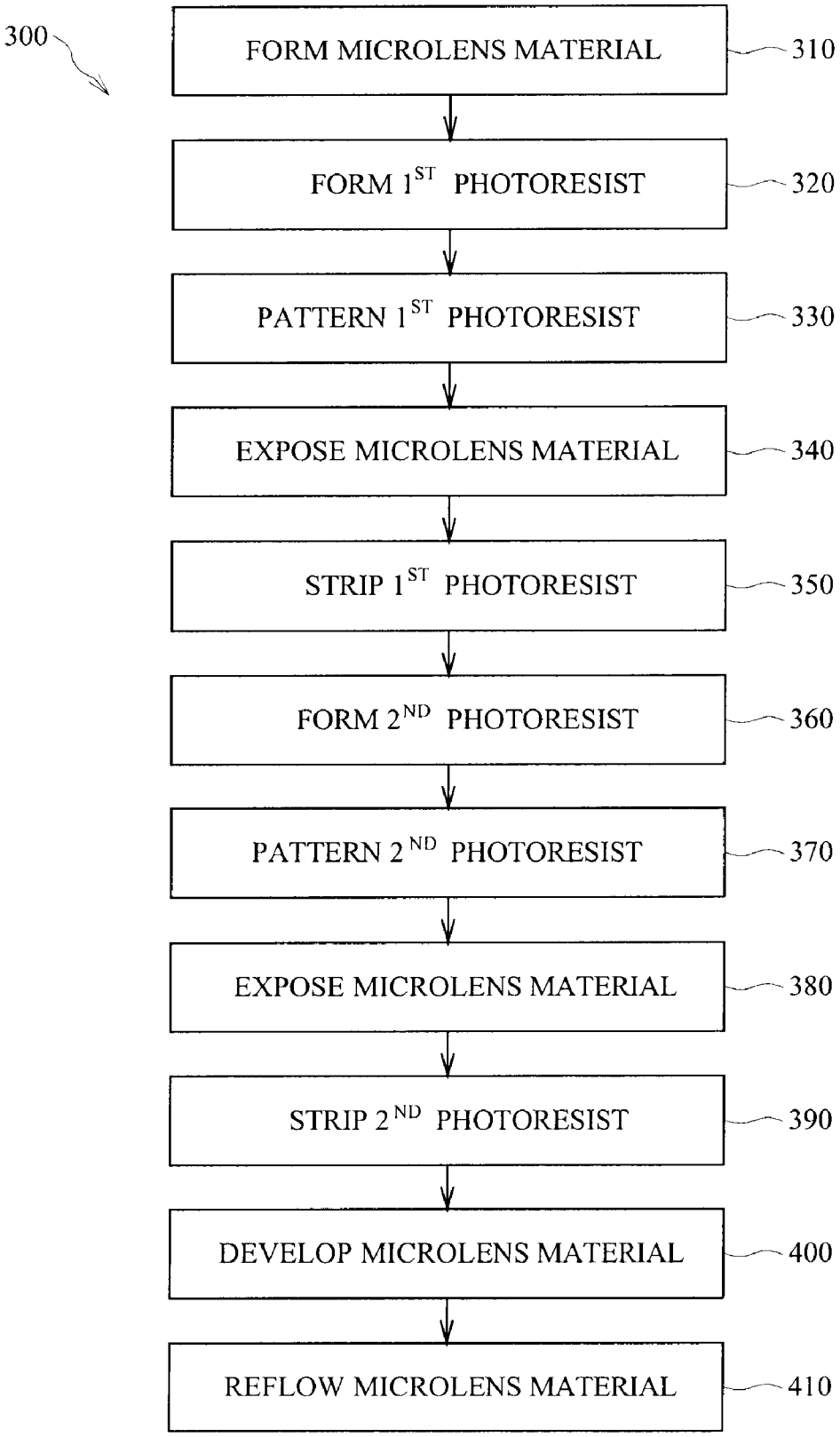

300
FORM MICROLENS MATERIAL
310
FORM 1ST PHOTORESIST
320
PATTERN 1ST PHOTORESIST
330
EXPOSE MICROLENS MATERIAL
340
STRIP 1ST PHOTORESIST
350
FORM 2ND PHOTORESIST
360
PATTERN 2ND PHOTORESIST
370
EXPOSE MICROLENS MATERIAL
380
STRIP 2ND PHOTORESIST
390
DEVELOP MICROLENS MATERIAL
400
REFLOW MICROLENS MATERIAL
410

Fig. 12

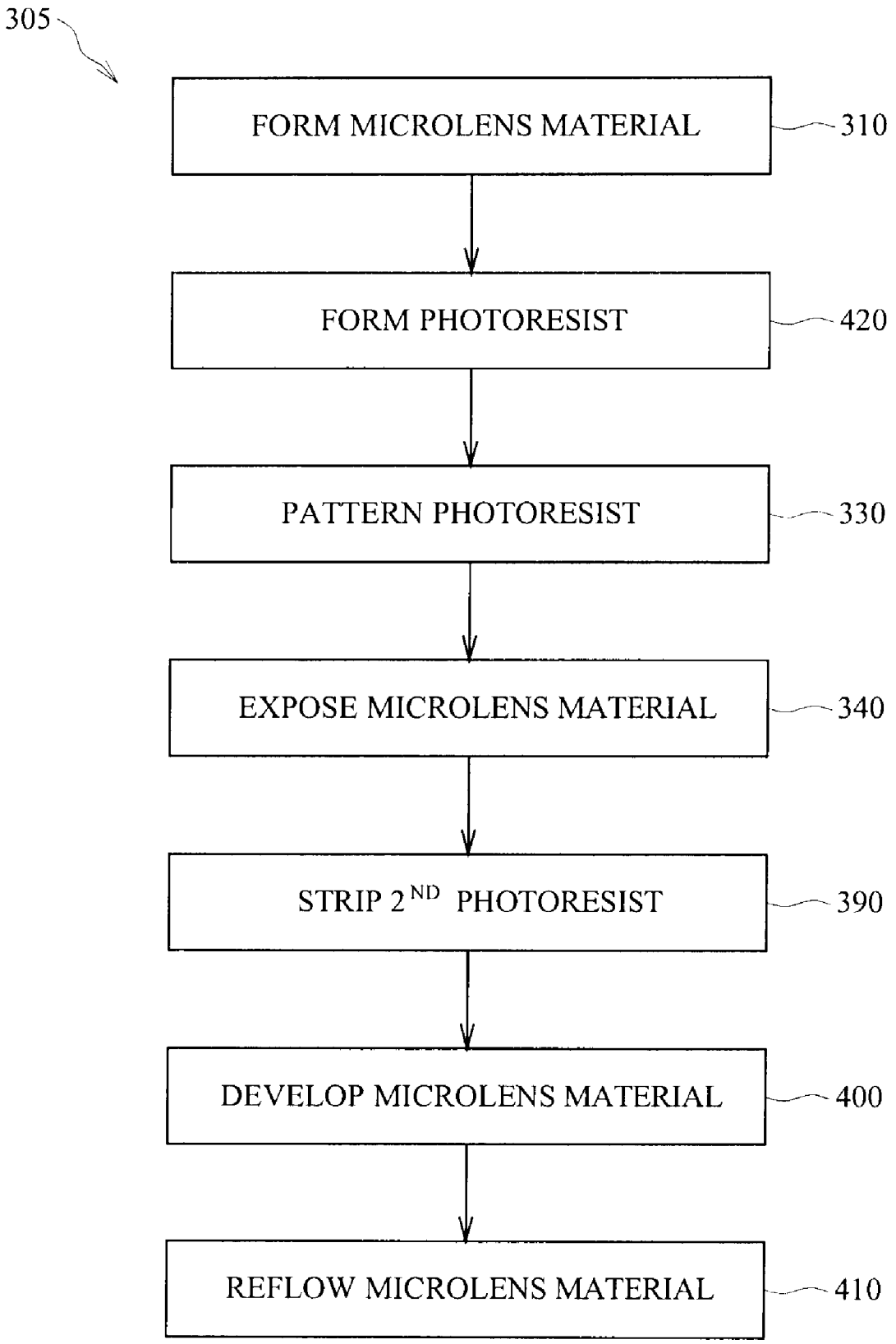

305
FORM MICROLENS MATERIAL
310
FORM PHOTORESIST
420
PATTERN PHOTORESIST
330
EXPOSE MICROLENS MATERIAL
340
STRIP 2ND PHOTORESIST
390
DEVELOP MICROLENS MATERIAL
400
REFLOW MICROLENS MATERIAL
410

Fig. 13

MICROLENS STRUCTURE FOR IMPROVED CMOS IMAGE SENSOR SENSITIVITY

BACKGROUND

Microlens arrays are widely employed in image sensor technology, such as charged coupling device (CCD) image sensors and complimentary metal-oxide-semiconductor (CMOS) image sensors. In general, CCD, CMOS, and other types of microlens arrays transform a light pattern (i.e., an image) into an electric charge pattern.

Microlens arrays are often formed by patterning a polymer layer formed over a color filter or array, a dielectric layer, and/or other substrate features. A subsequent reflow process and/or other heating method is then performed to heat the patterned polymer, thereby creating the required shape of each microlens. Each microlens is aligned over a corresponding photo-sensor formed in the underlying substrate. Consequently, light that is incident on each microlens is focused towards a corresponding photo-sensor.

A color filter may also be positioned between the microlens array and the underlying photo-sensor array, such that incident light focused by each microlens passes through the color filter prior to reaching a corresponding photo-sensor. Accordingly, specific wavelengths or wavelength ranges may be selectively blocked/permitted from reaching one or more of the photo-sensors. The color filter may be one or more substantially continuous layers that each substantially span the entire microlens array in a lateral direction (parallel to the substrate). Alternatively, the color filter may be segmented or otherwise subdivided into a plurality of filters each configured to block/permit different wavelengths. For example, such a filter array may include filters that only transmit red light, other filters that only transmit green light, and other filters that only transmit blue light.

However, when propagating in the same medium, blue light is more refractive than green light and red light, because the wavelength of blue light is about 430 nm, whereas the wavelengths for green and red lights are 550 nm and 600 nm, respectively. Consequently, once light passes through the color filter array, the resulting blue, green and red light will refract in different amounts along the propagation path leading towards the photo-sensor array. This can result in the one or more of the different wavelengths not being accurately focused on the photo-sensors, possibly decreasing the accuracy and reliability of the microlens-photo-sensor device.

BRIEF DESCRIPTION OF THE DRAWINGS

Aspects of the present disclosure are best understood from the following detailed description when read with the accompanying figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

FIG. **1** is a sectional view of at least a portion of a microlens-photo-sensor device according to one or more aspects of the prior art.

FIG. **2** is a magnified view of a portion of the device shown in FIG. **1**.

FIG. **3** is a sectional view of at least a portion of an embodiment of apparatus in an intermediate stage of manufacture according to one or more aspects of the present disclosure.

FIG. **4** is a sectional view of the apparatus shown in FIG. **3** in a subsequent stage of manufacture according to one or more aspects of the present disclosure.

FIG. **5** is a sectional view of the apparatus shown in FIG. **4** in a subsequent stage of manufacture according to one or more aspects of the present disclosure.

FIG. **6** is a top view of at least a portion of an embodiment of apparatus according to one or more aspects of the present disclosure.

FIG. **7** is a sectional view of the apparatus shown in FIG. **5** in a subsequent stage of manufacture according to one or more aspects of the present disclosure.

FIG. **8** is a sectional view of the apparatus shown in FIG. **7** in a subsequent stage of manufacture according to one or more aspects of the present disclosure.

FIG. **9** is a sectional view of the apparatus shown in FIG. **8** in a subsequent stage of manufacture according to one or more aspects of the present disclosure.

FIG. **10** is a sectional view of the apparatus shown in FIG. **4** in a subsequent stage of manufacture according to one or more aspects of the present disclosure.

FIG. **11** is a top view of at least a portion of an embodiment of apparatus according to one or more aspects of the present disclosure.

FIG. **12** is a flow-chart diagram of at least a portion of one embodiment of a method according to aspects of the present disclosure.

FIG. **13** is a flow-chart diagram of at least a portion of another embodiment of a method according to aspects of the present disclosure.

DETAILED DESCRIPTION

It is to be understood that the following disclosure provides many different embodiments, or examples, for implementing different features of various embodiments. 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 be limiting. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed. Moreover, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed interposing the first and second features, such that the first and second features may not be in direct contact.

Referring to FIG. **1**, illustrated is a sectional view of at least a portion of apparatus **10** according to one or more aspects of the prior art. The apparatus **10** may be or include a microlens-photo-sensor device. For example, the apparatus **10** includes a microlens array **15**, which includes a plurality of microlenses **17** that are each vertically or otherwise optically aligned with a corresponding one of a plurality of photo-sensors **20**. The photo-sensors **20** may include photodiodes and/or other sensors diffused or otherwise formed in the substrate **5**.

Aspects of the present disclosure are applicable and/or readily adaptable to microlens arrays employing charged coupling device (CCD) and complimentary metal-oxide-semiconductor (CMOS) image sensor applications (e.g., active-pixel sensors), among others. As such, the photo-sensors **20** may comprise conventional and/or future-developed image sensing devices.

The apparatus **10** may include or be at least temporarily formed on or from a substrate **5**, as well as a plurality of layers formed on the substrate **5**. For example, in the exemplary

embodiment depicted in FIG. **1**, a dielectric layer **25** formed on the substrate **5** electrically isolates each photo-sensor **20** from neighboring photo-sensors **20** (at least in a lateral direction relative to the substrate **5**).

The substrate **5** may comprise an elementary semiconductor (such as crystal silicon, polycrystalline silicon, amorphous silicon and germanium), a compound semiconductor (such as silicon carbide and gallium arsenide), an alloy semiconductor (such as silicon germanium, gallium arsenide phosphide, aluminum indium arsenide, aluminum gallium arsenide and gallium indium phosphide), combinations thereof, and/or other materials. The substrate **5** may also comprise a semiconductor material on an insulator, such as a silicon-on-insulator (SOI) substrate, a silicon on sapphire (SOS) substrate, or a thin film transistor (TFT) layer over glass and/or other materials.

The dielectric layer **25** may comprise silicon nitride (e.g., Si_3N_4), silicon oxynitride (e.g., $Si_xN_yO_z$), silicon oxide, silicon dioxide, and/or other materials. The dielectric layer **25** may be substantially optically transparent, and may be formed by chemical vapor deposition (CVD), plasma enhanced CVD (PECVD), physical vapor deposition (PVD), atomic layer deposition (ALD), evaporation, spin-on coating, and/or other processes. In one embodiment, the dielectric layer **25** has a thickness ranging between about 1 μm and about 50 μm, although other thicknesses are also within the scope of the present disclosure.

Another dielectric layer **30** is formed on the dielectric layer **25** and the photo-sensors **20**. The dielectric layer **30**, as with other layers and/or other features of the apparatus **10**, may include more than one layer, including multiple layers differing in composition and/or manufacture. The dielectric layer **30** may comprise silicon nitride (e.g., Si_3N_4), silicon oxynitride (e.g., $Si_xN_yO_z$), silicon oxide, silicon dioxide, and/or other materials. The dielectric layer **30** may also be a low-k dielectric layer having a dielectric constant less than or equal to about 3.9. The dielectric layer **30** may be formed by CVD, PECVD, PVD, ALD, evaporation, spin-on coating, and/or other processes. In one embodiment, the dielectric layer **30** has a thickness ranging between about 0.2 μm and about 50 μm, although other thicknesses are also within the scope of the present disclosure.

The dielectric layer **30** may include a plurality of optical stops **35** or similar structure defining a plurality of apertures each corresponding to the desired light propagation path from a corresponding microlens cell **17**. For example, the stops **35** may substantially eliminate or decrease the amount of light that is incident upon a particular photo-sensor **20** from any microlens cell **17** that does not correspond to the particular photo-sensor **20**. That is, each stop **35** and/or similar structure may substantially limit exposure of the particular photo-sensor **20** to the light propagating from the microlens cell **17** that is vertically aligned or otherwise corresponding to the photo-sensor **20**.

As also shown in the exemplary embodiment of FIG. **1**, a portion **32** of the dielectric layer **30** may be recessed relative to a thicker portion of the dielectric layer **30**. The apparatus **10** may include a contact, land, and/or other electrical interconnection feature **40** positioned with the recessed portion **32** of the dielectric layer **30**.

The apparatus **10** may also include a planar layer **45** located over at least a portion of the dielectric layer **20**. The planar layer **45** has a substantially planar upper surface **47** on which a color filter **50** is formed. The composition of the planar layer **45** may include conductive and/or dielectric materials. For example, the planar layer **45** may comprise silicon oxide and/or silicon nitride, among other materials. The planar layer **45** may also have at least some degree of optical transparency, including where the planar layer **45** is substantially optically transparent, among other embodiments. The planarity of the planar layer **45** may be achieved by chemical-mechanical planarizing ("CMP," also referred to as chemical-mechanical polishing). However, other planarizing methods may alternatively or additionally employed to render surface **47** as substantially planar, such as thermal flow, resist etch-back, sacrificial resist etchback, spin-on, and/or others. In one embodiment, for example, the planar layer **45** includes one or more layers that partially or substantially comprise a resin or polymeric material, such as a negative photoresist based on an acrylic polymer.

The color filter **50** is configured to absorb, deflect, and/or otherwise prevent the transmission of certain colors of incident light, thereby preventing such light from reaching the photo-sensors **20**. For example, the color filter **50** may allow only light of one particular wavelength to pass. However, as in the embodiment depicted in FIG. **1**, the color filter **50** may be an array of color filter elements each allowing light of one of several wavelengths to pass. For example, the color filter array **50** shown in FIG. **1** may include color filters **55***a* that pass only red light, color filters **55***b* that pass only green light, and color filters **55***c* that pass only blue light. Alternatively, the color filters **55***a* may pass only cyan light, the color filters **55***b* may pass only magenta light, and the color filters **55***c* may pass only yellow light. However, the color filter array **50** may not be limited to such red-green-blue (RGB) and cyan-magenta-yellow (CMY) configurations. For example, other embodiments of the color filter may be configured to pass other combinations of wavelengths and/or other numbers of wavelengths (e.g, fewer or greater than the three different wavelength filter elements shown in FIG. **1**).

The composition and manufacture of the color filter array **50** may be selected to suit the particular process technologies employed elsewhere in the manufacture of the device **10**. For example, such compositions and manufacturing processes may include those employed for volume production using 0.8 μm, 0.6 μm, 0.5 μm, 0.35 μm, 0.30 μm, 0.25 μm, 0.22 μm, 0.18 μm, 0.15 μm, 0.13 μm, 193 nm, 90 nm, 80 nm, 65 nm, 45 nm, and/or other process technologies, including those currently offered or projected by Taiwan Semiconductor Manufacturing Co. Ltd., among others. In one embodiment, the color filter array **50** comprises a negative photoresist based on an acrylic polymer including color pigments. The composition and/or manufacture of the color filter array **50** may be selected to achieve a desired pixilation, possibly depending on the ultimate end-use of the device **10**. For example, the device **10** may ultimately be employed in digital cameras, where the color filter array **50** may be suitable to achieve several million pixels.

The device **10** may also include a spacer layer **60**, such as may be employed to adjust the distance between the overlying microlens array **15** and the underlying photo-sensors **20**. For example, the spacer layer **60** may have a thickness ranging between about 0.2 μm and about 50 μm, although other thicknesses of the spacer layer **60** are also possible, as well as embodiments in which the spacer layer **60** is omitted. The spacer layer **60** may also have a composition that is substantially similar to that of the planar layer **45**, such as a composition that is substantially optically transparent, and may be formed by one or more processes similar to those employed to form the planar layer **45**.

The substrate **5**, photo-sensors **20**, dielectric layers **25** and **30**, aperture-defining features **35**, interconnection feature **40**, planar layer **45**, color filter **50**, spacer layer **60**, and microlens array **15** are conventional with regard to composition and/or

manufacture. For example, where such elements substantially comprise silicon dioxide, they may be formed by spin-on, ion implantation of oxygen, sputtering, thermal oxidation, atomic layer deposition (ALD), plasma-enhanced chemical vapor deposition (PECVD), low-pressure chemical vapor deposition (LPCVD), and/or high-density plasma (HDP-CVD), among other processes. Tetraethoxysilane (TEOS), for example, may be employed to form such a silicon dioxide element via PECVD. Additional examples include where such elements substantially comprise silicon nitride, in which case they may be formed by ion implantation of nitrogen, sputtering, ALD, PECVD, LPCVD, and/or HDP-CVD, among other processes. Hexachlorodisilane (HCD) and ammonia (NH_3), for example, may be employed to form such a silicon nitride element via LPCVD. Of course, other compositions and manufacturing processes may also be employed to form one or more of these elements.

In the depicted embodiment, the microlens array **15** is formed on the spacer layer **60** by first coating the spacer layer **60** with a microlens material. For example, the microlens material may include a resin or polymeric material, such as a negative photoresist based on an acrylic polymer. The microlens material is then exposed and developed by conventional photolithography processes, thereby defining a plurality of discrete microlens material elements each partially or substantially resembling a polyhedron. A reflow process and/or other heating method is then employed to form the convex profile of each microlens **17**. Consequently, each microlens **17** has substantially the same cross-sectional profile (shown in FIG. **1**) relative to each other microlens **17**. For example, each microlens **17** in the microlens array **15** extends to substantially the same height over the spacer layer (or in a direction that is normal to the surface **47** of the planar layer **45**), and each microlens **17** in the microlens array **15** has substantially the same curvature.

Referring to FIG. **2**, illustrated is a magnified view of a portion of the device **10** shown in FIG. **1**. A result of the above-described manufacturing process conventionally employed to form the microlens array **15** is that the microlens cells **17** have different focal lengths due to the variation of refractive indices of the different color filter elements **55***a-c*.

For example, the embodiment depicted in FIG. **2** includes a color filter element **55***a* configured to focus only blue light **56***a* onto photo-sensor **20***a*, a color filter element **55***b* configured to focus only green light **56***b* onto photo-sensor **20***b*, and a color filter element **55***c* configured to focus only red light onto photo-sensor **20***c*. However, the different colored light **56***a-c* propagates through portions of the planar layer **45** and the dielectric layer **30** that have the same thickness and refractive index. Consequently, because the wavelength of the blue light **56***a* is about 20% less than the wavelength of the green light **56***b* and about 30% less than the wavelength of the red light **56***c* when propagating through the same medium, the blue light **56***a* is more refractive than the green light **56***b* and the red light **56***c* when propagating through the planar layer **45** and the dielectric layer **30**. Thus, the blue light **56***a* has a shorter focal length **57***a* relative to the focal length **57***b* of the green light **56***b* and the focal length **57***c* of the red light **56***c*.

As a result, aspects of the microlens array **15** may be selected or configured such that the median of the three focal lengths **57***a-c*, which is focal length **57***b* in this example, results in a focal point **58***b* that is substantially coincident with its photo-sensor **20***b*. Additionally, the wavelengths of the green light **56***b* and the red light **56***c* differ by less than about 10%, such that the refraction of the red light **56***c* is substantially similar to the refraction of the green light **56***b*. Thus, the focal point **58***c* of the red light **56***c* is also substantially coincident with its photo-sensor **20***c*. However, because the refraction of the blue light **56***a* is substantially greater than the refraction of the green light **56***b*, the focal point **58***a* of the blue light **56***a* may not be coincident with its photo-sensor **20***a*, as depicted in FIG. **2**.

Referring to FIG. **3**, illustrated is a sectional view of at least a portion of an embodiment of apparatus **100** in an intermediate stage of manufacture according to one or more aspects of the present disclosure. The apparatus **100** may be substantially similar to the apparatus **10** shown in FIG. **1** and/or FIG. **2**, except as provided below.

The apparatus **100** includes a substrate **105** that is substantially similar to one or more of the substrate **5**, the dielectric layer **25**, and the photo-sensors **20** shown in FIG. **1**. For example, the substrate **105** may include elements such as the substrate **5** and/or the dielectric layer **25** shown in FIG. **1**. The substrate **105** or other portion of the apparatus **100** also includes an array of photo-sensors **120** which are substantially similar to the sensors **20** shown in FIG. **1**. The apparatus **100** also includes a dielectric layer **130** that is formed over the substrate **105** and which may be substantially similar to the dielectric layer **30** shown in FIG. **1**. The apparatus **100** also includes optical alignment features **135** that are embedded in the dielectric layer **130** and which may be substantially similar to the features **35** shown in FIG. **1**. The apparatus **100** also includes a planar layer **145** that is formed over the dielectric layer **130** and which may be substantially similar to the dielectric layer **30** shown in FIG. **1**. The apparatus **100** also includes a color filter array **150** that is formed over the planar layer **145** and which may be substantially similar to the color filter array **50** shown in FIG. **1**.

Referring to FIG. **4**, illustrated is a sectional view of the apparatus **100** shown in FIG. **3** in a subsequent stage of manufacture according to one or more aspects of the present disclosure, in which a microlens material **115** has been formed over the color filter array **150**. The microlens material **115** may be formed directly on the color filter array **150**. However, in other embodiments, one or more other layers may be formed on the color filter array **150** prior to forming the microlens material **115**. For example, prior to forming the microlens material **115** over the color filter array **150**, a spacer layer may be formed over the color filter array **150**, such as a layer that is substantially similar to the spacer layer **60** shown in FIG. **1**.

The microlens material **115** may comprise silicon nitride, a resin, or a polymeric material, such as a negative photoresist based on an acrylic polymer. The microlens material **115** may be formed over the color filter array **150** by one or more of spin-on processing, sputtering, photoresist coating processes, ALD, PECVD, LPCVD, and/or HDP-CVD, among other processes. In one embodiment, the composition and/or formation of the microlens material **115** over the color filter array **150** are substantially similar to the composition and/or formation of the microlens material employed to form the microlens cells **117** shown in FIG. **1**.

Referring to FIG. **5**, illustrated is a sectional view of the apparatus **100** shown in FIG. **4** in a subsequent stage of manufacture according to one or more aspects of the present disclosure, in which patterned photoresist elements **170** are formed over the microlens material **115**. The photoresist **170** may be conventional with regard to its composition and its deposition over the microlens material **115**, as well as with regard to its patterning. In one embodiment, the patterned photoresist **170** is formed by coating a positive or negative photoresist material over the microlens material **115** and subsequently performing one or more exposure processes and one or more development processes to define the desired

pattern. The pattern of the photoresist **170** may be substantially similar to the desired pattern of the microlens cells to be formed from the microlens material **115**, although the degree of such similarity may vary among different embodiments within the scope of the present disclosure.

Referring to FIG. **6**, illustrated is a top view of a portion of the apparatus **100** in the manufacture stage shown in FIG. **5**, depicting several of the patterned photoresist elements **170**. Each patterned photoresist element **170** may be substantially identical. For example, each patterned photoresist element **170** may have a substantially square footprint, such that its lateral dimensions d_1 and d_2 are substantially equal, as depicted in FIG. **6**. Moreover, each patterned photoresist element **170** may be substantially parallel to each neighboring element **170**, and/or may be laterally offset from each neighboring element **170** by the same dimension d_3, both of which being depicted in FIG. **6**. However, other shapes and orientations of the patterned photoresist elements **170** are also within the scope of the present disclosure.

After the patterned photoresist elements **170** are formed, such as in the embodiment shown in FIG. **6**, the microlens material layer **115** may undergo an initial exposure step. During such exposure, the photoresist elements **170** are employed as a mask, thereby preventing exposure of portions of the microlens material **115** corresponding to the photoresist elements **170** (e.g., those portions which are substantially underneath the photoresist elements **170** and, thus, substantially shielded from the exposure energy by the photoresist elements **170**). Thereafter, the patterned photoresist elements **170** may be stripped by etching or otherwise removed, leaving the partially exposed and undeveloped microlens material layer **115**.

Referring to FIG. **7**, illustrated is a sectional view of the apparatus **100** shown in FIG. **5** in a subsequent stage of manufacture according to one or more aspects of the present disclosure, in which patterned photoresist elements **172** are formed over the partially exposed and undeveloped microlens material **115**. The microlens material layer **115** may then undergo an additional exposure step to further expose those portions which correspond to pixels associated with shorter wavelengths and/or greater refraction between the color filter array **150** and the photo-sensors of the substrate **105**.

The patterned photoresist elements **172** may be substantially similar to the patterned photoresist elements **170** shown in FIGS. **5** and **6**. However, the number of patterned photoresist elements **172** formed on the microlens material **115** may be substantially less than the number of patterned photoresist elements **170** employed during the initial photolithographic exposure of the microlens material **115**, described above with respect to FIGS. **5** and **6**.

For example, where the apparatus **100** is intended to include a three-color pixilation scheme, the number of patterned photoresist elements **172** may be about 33% less than the number of patterned photoresist elements **170**. However, in some embodiments, the total number of pixels may not be evenly divided between the different colors of the pixels. For example, in an RGB pixilation scheme, the number of green pixels and/or red pixels may be double or otherwise substantially greater than the number of blue pixels. In such embodiments, the number of photoresist elements **172** may vary from the number of photoresist elements **170** by greater than or less than the 33% variation described above.

According to one embodiment, the number of photoresist elements **172** differs from the number of photoresist elements **170** by that number which, if all pixels were identical except for their color filter, equals the number of pixels that would have an insufficient focal length, such as the number of blue pixels in the RGB scheme described above with respect to FIGS. **1** and **2**. For example, in an RGB pixilation scheme, the number of photoresist elements **172** may be about equal to "X−Y" where "X" is the total number of pixels and "Y" is the total number of pixels of a specific color which require double photolithographic exposure to achieve an acceptable focal length.

Put another way, if the Red:Green:Blue pixel ratio is 5:4:3, such that there are five red pixels for every four green pixels and every three blue pixels, then the number of photoresist elements **172** may be about 75%, substantially complying with the 9:12 ratio of the number of red and green pixels, collectively, to the number of all pixels (red, green and blue pixels). Of course, the numbers used in this numerical example is hypothetical, devised merely to demonstrate how the quantity of photoresist elements **172** relates to the quantity of photoresist elements **170**. That is, the actual Red:Green:Blue pixel ratio may be about 1:1:1, 2:1:1, 1:2:1, or 2:2:1, among others. Thus, the ratio of the number of photoresist elements **172** to the number of photoresist elements **170** may be about 2:3, 3:4, or 4:5, among others.

In view of the above, it should be apparent to those skilled in the relevant art that the intended locations of the photoresist elements **172** substantially conform to the locations of pixels which have sufficient focal lengths when undergoing only one photolithographic exposure step or otherwise formed in a conventional manner. Consequently, the portions of the microlens material **115** that were protected during the initial photolithographic exposure step that employed the photoresist elements **170** but that are not protected by the photoresist elements **172** during the second photolithographic exposure step, such as those portions corresponding to blue pixels in a Red:Green:Blue pixilation scheme, will be exposed to the photolithographic exposure energy during the second photolithographic exposure step. However, the second photolithographic exposure step is less effective than the first photolithographic exposure step.

For example, the first photolithographic step is configured such that the exposed portions of the microlens material **115** (those not protected by the photoresist elements **170**) substantially span the thickness of the microlens material layer **115**, whereas the second photolithographic step is configured such that the additionally exposed portions of the microlens material **115** (those not protected by the photoresist elements **172**) only extend a portion into the thickness of the microlens material layer **115**. In another embodiment, the effectiveness of both photolithographic steps may be substantially equal with respect to the depth to which the resulting exposed portions extend into the microlens material layer **115**. That is, the first exposure step may expose about half the thickness of the microlens material **115** not protected by the photoresist elements **170**, and the second exposure step may expose the remaining thickness of these portions of the microlens material **115** while also exposing only a portion of the thickness of the portions of the microlens material **115** which were previously protected by the photoresist elements **170**.

In either scenario, and others within the scope of the present disclosure, the depth to which the portions of the microlens material **115** is exposed during the second exposure step (those portions previously protected by the photoresist elements **170** but not protected by the photoresist elements **172** during the second exposure step) may vary depending upon the particular embodiment. For example, the second exposure step may expose about 50% of the thickness of the portions of the microlens material **115** that are exposed for the first time during the second exposure step. However,

this value may range between about 20% and about 80% within the scope of the present disclosure.

Referring to FIG. **8**, illustrated is a sectional view of the apparatus **100** shown in FIG. **7** in a subsequent stage of manufacture according to one or more aspects of the present disclosure, in which the patterned photoresist elements **172** are removed, possibly in a manner substantially similar to the previously removal of the photoresist elements **170**. Thereafter, the double-exposed microlens material **115** is developed. As a result, as shown in FIG. **8**, the portions of the microlens material **115** that were protected by the photoresist elements **172** during the second exposure step have formed discrete microlens material elements **117***a*, while the portions of the microlens material **115** that were not protected by the photoresist elements **172** during the second exposure step have formed discrete microlens material elements **117***b*. The microlens material elements **117***a* and **117***b* are each substantially aligned over a corresponding, where the microlens material elements **117***a* are substantially greater in thickness relative to the microlens material elements **117***b*. The thickness of the microlens material elements **117***b* may be about 50% of the thickness of the microlens material elements **117***a*, although this value may range between about 20% and about 80% within the scope of the present disclosure.

Referring to FIG. **9**, illustrated is a sectional view of the apparatus **100** shown in FIG. **8** in a subsequent stage of manufacture according to one or more aspects of the present disclosure, in which the microlens elements **117***a* and **117***b* have undergone one or more reflow and/or other heating processes, thereby forming a microlens array **115'** comprising microlens cells **117***a*' and **117***b*'. The microlens cells **117***a*' and **117***b*' may be substantially similar to the microlens cells **17** of the microlens array **15** shown in FIGS. **1** and **2**. However, the microlens cells **117***a*' and **117***b*' vary in thickness. Thus, each microlens **117***b*' may be about half as thick as each microlens **117***a*', although other arrangements also are within the scope of the present disclosure. Moreover, as indicated by the dash lines in FIG. **9**, the focal lengths of each microlens **117***a*' and **117***b*' has been tailored such that the focal points of each microlens **117***a*' and **117***b*' substantially coincides with its corresponding photo-sensor **120**, despite the fact that the light passing through each of element of the color filter array **150** may substantially vary.

Referring to FIG. **10**, illustrated is a sectional view of another embodiment of the apparatus **100** shown in FIG. **5**, herein designated by reference numeral **200**. The manufacturing stage depicted in FIG. **10** is substantially the same as the manufacturing stage depicted in FIG. **5**, except as provided below.

That is, in the embodiment illustrated in FIG. **10**, patterned photoresist elements **270** have been formed over the microlens material layer **115**. The photoresist elements **270** are substantially similar in composition and manufacture to the photoresist elements **170** of FIG. **5**. However, the photoresist elements **270** are not all identical in shape, as described below.

FIG. **11** is a top view of at least a portion of the apparatus **200** shown in FIG. **10**. Referring to FIGS. **10** and **11**, collectively, some photoresist elements **270***a* have a larger footprint relative to the other photoresist elements **270***b*. All of the photoresist elements **270***a* and **270***b* may still have a substantially square-shaped footprint, although other shapes are also within the scope of the present disclosure. The lateral dimensions d_4 and d_5 of the photoresist elements **270***a* may be about 20% larger than the lateral dimensions d_1 and d_2 of the photoresist elements **270***b*, although this difference may also range between about 5% and about 50% within the scope of the present disclosure. However, the lateral pitch of the photoresist elements **270***a* and **270***b* may remain substantially constant despite the larger size of the photoresist elements **270***a*, such that the lateral offset d_6 of each photoresist element **270***a* from each neighboring photoresist element **270***b* may be about 30% to 40% less than the lateral offset d_3 between two neighboring photoresist elements **270***b*.

The photoresist elements **270***a* correspond to those pixels requiring a lens having a longer focal length, such as the photoresist elements **170** of FIG. **5** that were not replaced by photoresist elements **172** of FIG. **7**. For example, the photoresist elements **270***a* may correspond to the blue pixels in a Red-Green-Blue pixilation scheme, whereas the photoresist elements **270***b* may correspond to the red and green pixels. The photoresist elements **270***a* are also semi-translucent to the photolithography energy subsequently employed to transfer the pattern of the photoresist elements **270***a* and **270***b* to the microlens material layer **115**. The photoresist elements **270***b* may also be semi-translucent, although not to the same extent as the photoresist elements **270***a*.

As a result, the portions of the microlens material **115** which lay substantially under the photoresist elements **270***a* will be partially exposed during the photolithographic exposure step. That is, an upper portion will be exposed, while a lower portion will not be exposed. Consequently, the microlens elements **117***a* and **117***b* shown in FIG. **8** can then be defined from the microlens material **115** via a photolithography development step. Thereafter, one or more reflow and/or other heating processes may be employed to form the microlens cells **117***a*' and **117***b*' shown in FIG. **9**.

Thus, according to one or more aspects of the present disclosure, a microlens array may be formed via conventional materials and processes over a color filter array and photo-sensor array that are also formed via conventional materials and processes, yet the microlens array may also include lenses of different focal lengths to compensate for the variation of refraction associated with the different wavelengths of light propagating from the color filter array towards the photo-sensor array. Consequently, the amount of color-filtered light that is incident upon each photo-sensor array may be substantially similar or equal.

These and/or other possible advantages may be achieved via aspects of one or more embodiments of methods employed in the manufacture of microlens devices within the scope of the present disclosure. One such method **300** is at least partially depicted in FIG. **12** as a flow-chart diagram.

The method **300** includes forming a microlens material over a color filter array and a photo-sensor array in step **310**. A first photoresist layer is then formed over the microlens material in step **320**. The first photoresist layer is then patterned in step **330** to form first photoresist elements that substantially correspond in shape, location and orientation to the individual optical elements of the microlens array being formed. The first photoresist elements are then employed in step **340** to initially expose portions of the microlens material that lie outside the perimeter boundaries of each optical element of the microlens array being formed.

The first photoresist elements are then stripped away in step **350**, and a second photoresist layer is formed over the partially exposed microlens material in step **360**. The second photoresist layer is then patterned in step **370** to form second photoresist elements that substantially correspond in shape, location and orientation to the individual optical elements of the microlens array that will correspond to the red and green pixels, or to the pixels that have sufficient focal length when manufactured conventionally. The second photoresist elements are then employed in step **380** to additionally expose

portions of the microlens material that lie within the perimeter boundaries of those optical elements of the microlens array that require longer focal lengths, such as blue pixels.

The second photoresist elements are then stripped away in step **390**, and the twice-exposed microlens material layer is developed in step **400**, thereby defining discrete microlens material elements of different heights corresponding to the wavelength to which each color filter element is configured to transmit. The discrete microlens material elements of different heights then undergo a reflow process in step **410**, which defines the convex, lens-shaped surface of each microlens. As a result, an increased focal length is achieved for each optical element of the microlens array that corresponds to a pixel which would otherwise suffer from lowered sensitivity due to shorter wavelength.

Referring to FIG. **13**, illustrated is a flow-chart diagram of at least a portion of another embodiment of the method **300** shown in FIG. **12**, and designated herein by reference numeral **305**. The method **305** includes forming a microlens material over a color filter array and a photo-sensor array in step **310**. A photoresist layer is then formed over the microlens material in step **420**. After subsequent patterning in step **330**, the photoresist layer includes first and second photoresist elements that each substantially correspond in shape, location and orientation to an individual optical element of the microlens array. The first photoresist elements each correspond to pixels that have sufficient focal length when manufactured conventionally (e.g., red and green pixels in a Red-Green-Blue scenario), while the second photoresist elements each correspond to pixels that have insufficient focal length when manufactured conventionally (blue pixels in a Red-Green-Blue scenario). The second photoresist elements have greater translucency to photolihtogaphic exposure energy, relative to the first photoresist elements. For example, the first photoresist elements may be substantially opaque, while the second photoresist elements may be semi-translucent (e.g., half-way between translucent and opaque).

The first and second photoresist elements are then employed in step **340** to expose portions of the microlens material. The portions of the microlens material that were protected by the first photoresist elements are protected from the exposure energy, at least to a greater extent than the degree to which the portions of the microlens material that were partially protected from the exposure energy by the at least partially translucent second photoresist elements.

The first and second photoresist elements are then stripped away in step **390**, and the exposed microlens material layer is developed in step **400**, thereby defining discrete microlens material elements of different heights corresponding to the wavelength to which each color filter element is configured to transmit. The discrete microlens material elements of different heights then undergo a reflow process in step **410**, which defines the convex, lens-shaped surface of each microlens. As with the method **300**, an increased focal length is achieved for each optical element of the microlens array that corresponds to a pixel which would otherwise suffer from lowered sensitivity due to shorter wavelength.

In view of the above, the present disclosure introduces a method of manufacturing a microlens device that includes, at least in one embodiment, depositing a microlens material layer over a substrate, wherein the substrate includes photo-sensors located therein. Portions of the microlens material layer are then exposed and developed to define microlens material elements. The microlens material elements include first microlens material elements and second microlens material elements, wherein each of the second microlens material elements are substantially greater in thickness relative to each of the first microlens material elements. The microlens material elements are then heated to form a microlens array. The microlens array includes first microlens array elements each corresponding to one of the first microlens material elements, and also includes second microlens array elements each corresponding to one the second microlens material elements, wherein each of the second microlens array elements is substantially greater in thickness relative to each of the first microlens array elements.

In one embodiment, the microlens device manufacturing method includes depositing the microlens material layer over the substrate, exposing and developing portions of the microlens material layer to define first and second microlens material elements, and heating the microlens material elements to form a microlens array that includes first and second microlens array elements, wherein each of the first microlens array elements has a substantially greater focal length relative to each of the second microlens array elements.

The present disclosure also introduces a microlens device that includes, at least in one embodiment, photo-sensors located in a substrate, a color filter array, and at least one optically transparent layer located between the color filter array and the photo-sensors. A microlens array is located over the color filter array. The microlens array includes first microlens array elements each having a first focal length and second microlens array elements each having a second focal length, wherein the first and second focal lengths are substantially different.

The foregoing has outlined features of several embodiments so that those skilled in the art may better understand the various aspects of the present disclosure. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions and alterations herein without departing from the spirit and scope of the present disclosure.

What is claimed is:

1. A microlens device, comprising:

a plurality of photo-sensors located in a substrate;

a color filter array;

at least one optically transparent layer located between the color filter array and the plurality of photo-sensors; and

a microlens array located over the color filter array and including:

a plurality of first microlens array elements each having a first focal length, and

a plurality of second microlens array elements each having a second focal length,

wherein the first and second focal lengths are substantially different and wherein a thickness of each of the plurality of second microlens array elements is substantially less than a thickness of one of the plurality of first microlens array elements.

2. The microlens device of claim **1** wherein the microlens array has a Composition that at least partially includes a polymer material.

3. The microlens device of claim **1** wherein the color filter array includes:

a plurality of first filter elements each configured to transmit light of a first wavelength, and

a plurality of second filter elements each configured to transmit light of a second wavelength that is substantially different than the first wavelength.

4. The microlens device of claim **3** wherein the color filter array further includes a plurality of third filter elements each configured to transmit light of a third wavelength that is substantially different than the second wavelength.

5. The microlens device of claim **4** wherein the first wavelength is that of red light, the second wavelength is that of blue light, and the third wavelength is that of green light.

6. The microlens device of claim **1** wherein the thickness of each of the plurality of second microlens array elements is about 20% to 80% of the thickness of one of the plurality of first microlens array elements.

7. The microlens device of claim **6** wherein the thickness of each of the plurality of second microlens array elements is about 50% of the thickness of one of the plurality of first microlens array elements.

8. A microlens device, comprising:

a plurality of photo-sensors located in a substrate;

a color filter array;

at least one optically transparent layer located between the color filter array and the plurality of photo-sensors; and

a microlens array located over the color filter array and including:

a plurality of first microlens array elements each having a first focal length, and

a plurality of second microlens array elements each having a second focal length,

wherein the first and second focal lengths are substantially different;

wherein: the color filter array includes a plurality of first filter elements that are each configured to transmit light of a first wavelength, and that are each optically aligned with a corresponding one of the plurality of first microlens array elements,

the color filter array further includes a plurality of second filter elements that are each configured to transmit light of a second wavelength, and that are each optically aligned with a corresponding one of the plurality of second microlens array elements,

the second wavelength is substantially less than the first wavelength, and

the second focal length is greater than the first focal length.

9. The microlens device of claim **8** wherein:

the color filter array includes a plurality of third filter elements that are each configured to transmit light of a third wavelength, and that are each optically aligned with a corresponding one of the plurality of first microlens array elements, and

the second wavelength is substantially less than the third wavelength.

10. A microlens device, comprising:

a plurality of photo-sensors located in a substrate;

a color filter array;

at least one optically transparent layer located between the color filter array and the plurality of photo-sensors; and

a microlens array located over the color filter array and including:

a plurality of first microlens array elements each having a first focal length, and

a plurality of second microlens array elements each having a second focal length,

wherein the first and second focal lengths are substantially different;

wherein: the color filter array includes a plurality of red-light filter elements each optically aligned with a corresponding one of the plurality of first microlens array elements,

the color filter array further includes a plurality of green-light filter elements each optically aligned with a corresponding one of the plurality of first microlens array elements,

the color filter array further includes a plurality of blue-light filter elements each optically aligned with a corresponding one of the plurality of second microlens array elements, and

the second focal length is greater than the first focal length.

* * * * *