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(54) Title: OPTICAL MODULES INCLUDING FOCAL LENGTH ADJUSTMENT AND FABRICATION OF THE OPTICAL MODULES

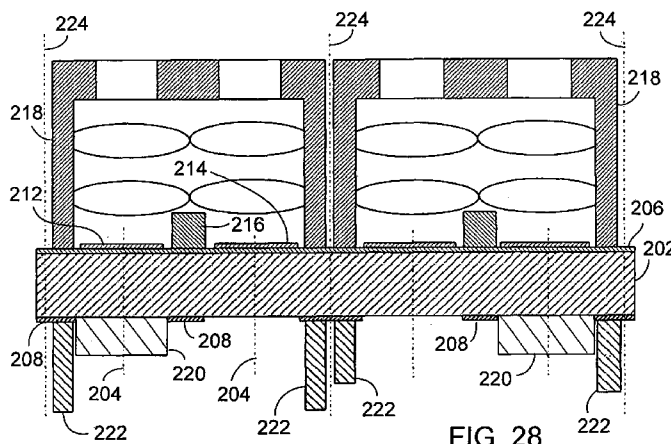


FIG. 28

(57) Abstract: Fabricating optical devices can include mounting a plurality of singulated lens systems over a substrate, adjusting a thickness of the substrate below at least some of the lens systems to provide respective focal length corrections for the lens systems, and subsequently separating the substrate into a plurality of optical modules, each of which includes one of the lens systems mounted over a portion of the substrate. Adjusting a thickness of the substrate can include, for example, micro-machining the substrate to form respective holes below at least some of the lens systems or adding one or more layers below at least some of the lens systems so as to correct for variations in the focal lengths of the lens systems.

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## **OPTICAL MODULES INCLUDING FOCAL LENGTH ADJUSTMENT AND FABRICATION OF THE OPTICAL MODULES**

### **FIELD OF THE DISCLOSURE**

[0001] This disclosure relates to optical modules for cameras and other devices. It also relates to methods of manufacturing such modules using wafer-scale manufacturing steps.

### **BACKGROUND**

[0002] During the manufacture of devices, in particular optical devices, manufacturing irregularities or manufacturing deviations may occur, for example, because of more or less unavoidable variations or inaccuracies in one or more of the process steps. For example, when the optical device includes one or more lens elements, a multitude of such lens elements on a wafer (referred to as an optics wafer) typically would have slightly varying focal lengths despite having the same nominal focal length. In some cases, the focal length may correspond to the flange focal length (FFL), which refers to the distance between the last physical plane of the device (i.e., the physical plane of device that is closest to sensor) and the focal plane of the device's lens system. More generally, the focal length may refer to any focal length parameter (e.g., the effective focal length (EFL)). In any event, variations in the focal lengths can result in the focal plane of the lens system lying off the image sensor plane, which can lead to inferior image quality.

### **SUMMARY**

[0003] The present disclosure describes optical devices and methods of fabricating the optical devices. Various approaches are described to provide focal length adjustments for the lens systems to correct for variations in the focal lengths of the lens systems.

[0004] For example, in one aspect, a method of fabricating optical devices includes mounting a plurality of singulated lens systems over a substrate, adjusting a thickness of the substrate below at least some of the lens systems to provide respective focal length corrections for the lens systems, and subsequently separating the substrate into a plurality

of optical modules, each of which includes one of the lens systems mounted over a portion of the substrate. In some implementations, adjusting a thickness of the substrate can include micro-machining to form respective holes below at least some of the lens systems so as to correct for variations in the focal lengths of the lens systems. In some implementations, adjusting a thickness of the substrate can include adding one or more layers below at least some of the lens systems so as to correct for variations in the focal lengths of the lens systems.

[0005] In another aspect, a method of fabricating optical devices includes placing a plurality of individual lens stacks on a substrate, micro-machining the substrate at positions below one or more of the lens stacks to adjust focal lengths for the lens stacks, and subsequently dicing the substrate into a plurality of optical modules, each of which includes one or more of the lens stacks on respective portions of the substrate.

[0006] The described fabrication techniques can be advantageous in some implementations because they allow the individual lens systems to be tested prior to being mounted on a flange focal length (FFL) correction substrate. Such testing allows only those lens stacks that satisfy specified requirements (e.g., pass the optical or other tests) to be selected for use in the subsequent fabrication steps and to be mounted on the FFL correction substrate.

[0007] According to yet another aspect, a method of fabricating optical devices includes attaching a plurality of lens systems to a first side (i.e., lens stack side) of a substrate composed of a material that is substantially transparent to light of a predetermined wavelength or range of wavelengths, providing a channel FFL correction layer on a second side (i.e., sensor side) of the substrate; and removing selected portions of the channel FFL correction layer so as to adjust for respective focal length variations for at least some of the lens systems. In some implementations, instead of removing selected portions of the channel FFL correction layer so as to adjust for the respective focal length variations, one or more channel FFL correction layers are provided where needed to correct for the focal length variations.

[0008] According to a further aspect, an apparatus includes a substrate having a thickness that varies from one area of the substrate to another area. A plurality of singulated optical systems mounted over the substrate, wherein respective ones of the optical systems are disposed over different areas of the substrate so as to provide focal length corrections to at least some of the optical systems. The thicknesses of the different areas of the substrate can be provided, for example, so as to correct for variations in the focal lengths of the lens systems.

[0009] In another aspect, an optical module includes a substrate composed of a material that is transparent to light of a particular wavelength of range of wavelengths, and a plurality of lens systems attached over a first side of the substrate, wherein each lens system has a respective optical axis that intersects the substrate and corresponds to a respective optical channel in the module. The module includes a plurality of color filter layers disposed over different regions of the substrate, wherein the optical axis of each lens system intersects a respective one of the color filter layers. A spacer is disposed over the substrate between a respective pair of the color filter layers, and is substantially non-transparent to light of the particular wavelength of range of wavelengths. A non-transparent (e.g., black) coating also can be provided on a bottom surface of the substrate. The module includes a channel FFL correction layer, wherein the optical axis of at least one of the lens systems intersects the channel FFL correction layer. A module FFL correction layer also can be provided. An image sensor is attached over a second side of the substrate.

[0010] Modules that include multiple optical channels as well as single channel modules are described. In some cases, the thickness of a FFL correction substrate can be adjusted, as needed, to provide FFL correction for individual channels of a multi-channel module, and spacers can be provided to provide FFL correction for the module as a whole. In situations where the module includes only a single optical channel, spacers can be provided, and their height adjusted to provide a desired FFL correction for the optical channel.

[0011] In some cases, instead of mounting singulated lens systems on a FFL correction substrate, an optics/spacer stack that includes multiple lens stacks is attached to the FFL correction substrate.

[0012] Other aspects, features and advantages will be apparent from the following detailed description, the accompanying drawings and the claims.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. 1 is a flow chart of a method according to the present invention.

[0014] FIGS. 2 through 5 illustrate steps according to a first fabrication process.

[0015] FIG. 6 is an example of an optical module resulting from the first fabrication process.

[0016] FIGS. 7 through 9 illustrate steps according to a second fabrication process.

[0017] FIGS. 10 and 11 illustrate examples of lens stack arrays on a FFL correction layer.

[0018] FIGS. 12 and 13 illustrated examples of FFL correction substrates that include multiple FFL correction layers.

[0019] FIGS. 14 and 15 illustrate examples of lens stack arrays on FFL multi-layer substrates.

[0020] FIGS. 16 and 17 illustrate examples of FFL correction substrates with additional features.

[0021] FIGS. 18-24, 24A - 24B, 25, 25A and 26 - 29 illustrate examples fabrication processes for making a sensor module that includes an array of lens stacks mounted on a FFL correction structure.

[0022] FIGS. 30 through 32 illustrate other examples of modules that include an array of lens stacks with a FFL correction structure.

[0023] FIG 33 illustrates an example of a single channel module according to the present invention.

[0024] FIG 34 illustrates a wafer-level technique for fabricating single channel modules.

[0025] FIGS. 35 through 38 illustrate a wafer-level technique for forming an optics/spacer stack that includes multiple lens stacks.

## DETAILED DESCRIPTION

[0026] As indicated by FIG. 1, a method of fabricating multiple optical modules can include performing various steps at the wafer-level and incorporates features for correcting or otherwise adjusting focal length variations of optical elements in each device. In the present context, a wafer can be composed, for example, of a polymer material (e.g., a hardenable material such as a thermally or UV-curable polymer), a glass material, a semiconductor material, or a composite material comprising metals and polymers or polymers and glass materials. In general, a wafer refers to a substantially disk- or plate-like shaped item, such that its dimension in one direction (the z-direction or vertical direction) is small with respect to its extension in the other two directions (the x- and y-directions or lateral directions). Multiple similar structures or items can be arranged or provided on or in a (non-blank) wafer, for example, on a rectangular grid. The wafer can have openings (i.e., holes), and a wafer may even be free of material in a predominant portion of its lateral area.

[0027] As indicated by FIG. 1, multiple lens stacks can be fabricated, for example, as part of a wafer level process (block 20). The lens stacks are separated from one another into individual lens stacks using dicing or other techniques (block 22). Some, or all, of the individual lens stacks then are mounted (e.g., attached) on a FFL correction substrate (block 24), which as explained below may include one or more FFL correction layers. The lens stacks can be mounted on the FFL correction substrate, for example, using a bonding material such as glue or an epoxy resin. As part of the focal length variation correction or adjustment, the focal length of each lens stack can be measured individually. The focus length variations of the lens stacks are adjusted or corrected, for example, by micromachining the FFL correction substrate (block 26). The micromachining step may include, for example, milling, drilling, laser ablation, etching and/or photolithography, as well as other techniques. The individual lens stacks then can be separated by dicing or some other process (block 28).

[0028] Although some of the foregoing steps are performed at the wafer level, mounting the individual lens stacks onto the FFL correction substrate (i.e., block 24) preferably is performed by placing individual (i.e., singulated) lens stacks onto the FFL correction substrate. Such a method can be advantageous because it allows the individual lens stacks to be tested prior to being mounted on the FFL correction substrate. Such testing allows only those lens stacks that satisfy specified requirements (e.g., pass the optical or other tests) to be selected for use in the subsequent fabrication steps and to be mounted on the FFL correction substrate. Nevertheless, one, two or more lens stacks may be placed simultaneously on the FFL correction substrate.

[0029] FIGS. 2-5 illustrate an example of the method for fabricating multiple optical modules. As shown in FIG. 2, a wafer-level process is used to form multiple lens stacks 40 by attaching multiple wafers to form a wafer stack. In this example, each lens stack 40 includes pairs of passive optical components, such as plastic lenses 42A-42C and 44A-44C, arranged vertically one above another. Replication or other techniques can be used to form lenses on respective surfaces of optics wafers 46A, 46B which can be attached to one other by spacer wafers 48A, 48B. The lenses can redirect light, for example, by refraction and/or by diffraction. Thus, the lenses may be of generally convex shape or may be differently shaped, e.g., generally or partially concave. Each of lenses 42A-42C and 44A-44C can have a nominal focal length; for example, lenses 42A-42C can have the same first nominal focal length, and lenses 44A-44C can have the same second nominal focal length so that the overall focal length for each lens stack is about the same. However, in practical applications, the focal lengths of the lenses may deviate from their respective nominal focal lengths (e.g., as a result of manufacturing limitations).

[0030] In the illustrated example, baffles 50 are provided around the opening at the top of each lens stack 40. Baffles 50 can prevent undesired light from entering or leaving lens stack 40 at particular angles. Baffles 50 can be composed, for example, of a material that substantially attenuates or blocks light at a particular wavelength or in a wavelength range.

[0031] The wafer stack of FIG. 2 is then diced into individual lens stacks 40, an example of which is illustrated in FIG. 3. The individual lens stacks 40 then can be tested, and those lens stacks that satisfy any testing requirements or other specifications are mounted on a FFL correction substrate 52, as shown in FIG. 4. The optical axes for the optical channels are indicated by the dashed lines 41. FFL correction substrate 52 can be composed, for example, of a transparent material (e.g., glass) with specified properties (e.g., to allow light of a particular wavelength or within a particular wavelength range to pass with little or no attenuation).

[0032] The focal length of each lens stack 40 mounted on FFL correction substrate 52 is measured, and the offset in relation to the image plane of the sensor is determined. Based on the resulting measurements, FFL correction substrate 52 is micro-machined (if needed) to correct the focal length variation for each lens stack 40. The micro-machining can include forming a hole or other opening 54 in the sensor side of FFL correction substrate 52 below a particular lens stack 40. The depth of holes 54 may vary and, in some cases, no hole may be needed for one or more of the lens stacks 40 (e.g., if no correction or adjustment to the focal length is needed). The holes provide air spaces which result in adjustments to the respective focal length variations for the lens stacks. The index of refraction of the material of substrate 52 is different from (e.g., greater than) the index of refraction of vacuum or air in the holes 54. Thus, by adjusting the depths of each hole 54 in dependence of the deviation of the focal length of the associated optical components from the respective nominal focal length, deviations can be compensated, at least to some degree. The depths of the holes can be selected, for example, so that the resulting focal lengths of all the lens stacks are substantially the same as one another. Alternatively, the FFL correction layer can be adjusted by photolithographic techniques, which can be particularly helpful when several layers of FFL correction layers are used (see FIGS. 26 and 27). This can be particularly useful, for example, for fabrication of optical devices that include an array of lenses.

[0033] After mounting lens stacks 40 on FFL correction substrate 52, the gaps between adjacent lens stacks can be filled (or partially filled) with a non-transparent material 56 (e.g., black epoxy) so that each lens stack is surrounded by non-transparent walls that help prevent stray light from entering the lens stack during subsequent use. FFL correction substrate 52 (and non-transparent material 56, if present) then is diced or otherwise separated to form individual optical modules each of which includes a lens stack 40 with FFL correction. An example of such an optical module 60 is illustrated in FIG. 6.

[0034] In the example of FIGS. 2-6, each lens stack 40 includes an array of lenses aligned vertically with one another. In other implementations, the lens stack may include a different number of lenses, different types of lenses, or a different arrangement of lenses. Thus, lens stack 40 is an example of a lens system that can be incorporated into optical module 60. The lens system can include one or more lenses or other passive optical elements, which may be focused or non-focused.

[0035] In the example of FIGS. 2-6, lens stacks 40 are fabricated using a wafer-level process that includes stacking multiple substrate wafers one atop the other to form a wafer stack that subsequently is diced to provide the individual lens stacks. In other implementations, the lens stacks can be made using an injection molding technique. For example, as shown in FIGS. 7 and 8, one or more plastic lenses 70, 72 made by injection molding are introduced into a lens barrel or other lens holder 74 to form a lens system, in this case a lens stack 80. Lens barrel 74 can be formed, for example, of non-transparent material such as a thermoplastic material (e.g., polycarbonate with fillers or a liquid crystal polymer with glass fibers) and includes an opening 76 at its top end to allow light to enter or exit.

[0036] Lens stacks 80 then can be mounted on a FFL correction substrate 52 in a manner similar to that described above in connection with FIG. 4 (i.e., individual singulated lens stacks 80 are mounted on FFL correction substrate 52). The focal length of each lens stack 80 mounted on FFL correction substrate 52 is measured, and based on the resulting

measurements, FFL correction substrate 52 is micro-machined (if needed) to adjust the focal length variation for each lens stack 80. As described above in connection with FIG. 5, the micro-machining can include forming a hole 54 in the sensor-side surface of FFL correction substrate 52 below a particular lens stack 80 (see FIG. 9). The depth of holes 54 may vary and, in some cases, no hole may be needed for one or more of the lens stacks 80 (e.g., if no correction or adjustment to the focal length is needed). FFL correction substrate 52 then can be diced or otherwise separated to form individual optical modules each of which includes a lens stack 80 with FFL correction.

[0037] In the foregoing illustrated examples, each module includes a single lens stack. However, in other implementations, each module can include two or more lens stacks. In some cases, each module includes an array of lens stacks (e.g., a 2x2 array, a 3x3 array, a 4x4 array, or a MxN array, where M and N are positive integers that may be the same or different from one another). In such implementations, MxN arrays of lens stacks can be attached to a FFL correction substrate 52 as illustrated, for example, in FIGS. 10 and 11. FIG. 10, for example, illustrates MxN arrays of lens stacks 40 that were manufactured in a wafer-level technique, whereas FIG. 11 illustrates MxN arrays of lens stacks 40 formed by an injection molding technique. After dicing FFL correction layer 52, each module will include multiple lens stacks aligned side-by-side.

[0038] FFL correction substrate 52 can be composed of a single layer as in the examples of FIGS. 5 and 9. However, in other implementations, FFL correction substrate 52 can include multiple layers of different materials depending on the desired optical properties for the resulting optical modules. For example, FIG. 12 illustrates an example in which the FFL correction substrate is composed of a bottom layer 52A and a top layer 52B. In the illustrated example, holes for the FFL correction are formed in bottom layer 52A. FIG. 13 illustrates an example in which the FFL correction layer includes a bottom layer 52C, a middle layer 52D and a top layer 52E. In the illustrated example, holes 54 for the FFL correction are formed in bottom layer 52C. The various FFL layers can be composed, for example, of glass materials and/or polymer materials. MxN arrays of lens stacks also can be mounted on multi-layer FFL correction substrates. Examples are

illustrated in FIGS. 14 and 15, which show, respectively,  $M \times N$  arrays of lens stacks 40 on an FFL correction substrate 52 composed of multiple layers 52A, 52B of different materials. In some implementations, the FFL correction substrate may be composed of more than two different layers.

[0039] In some implementations, one or more color filters and/or infra-red (IR) filters can be provided on FFL correction substrate 52 to obtain desired optical properties for the resulting optical modules. Color filters can include, for example, monochromous red, green and blue filters, or Bayer pattern filters. Also, in some implementations, IR filters or neutral density filters can be provided. An example is illustrated in FIG.16, which includes an IR filter layer 90 on the lens stack side of FFL correction substrate 52 and color filters 92 on the IR filter layer. Color filters are disposed at locations that correspond to optical channels for each lens stacks (e.g., lens stacks 40 or 80). Thus, a lens stack 40 (or 80) can be mounted, for example, on or over each of the color filters 92.

[0040] Furthermore, in some implementations, each optical module includes multiple lens stacks. For example, a first lens stack may be aligned with a light emitting element (e.g., a LED), and a second lens stack may be aligned with a light detecting element (e.g., a photodiode). In that case, the color filters 92 on FFL correction substrate 52 may have different optical properties from one another, and a cross channel stray light reduction feature can be provided between the two channels. As illustrated in FIG. 16, cross channel stray light reduction can be implemented by a black spacer 96 atop a black coating layer 94. In some implementations, black spacer 96 is applied directly to FFL correction substrate 52 or IR filter layer 90 (i.e., without black coating layer 94). Black spacer 96 and black coating layer 94 are substantially non-transparent to light over a predetermined range of wavelengths (e.g., in the visible part of the spectrum, the IR part of the spectrum, and/or the UV part of the spectrum). Suitable coating techniques include, for example, spin coating, spraying and sputtering. Such coating techniques can be used to provide black coating layer 94, IR filter layer 90, and/or color filter coating 92. Multiple lens stacks 40 (or 80) can be mounted on a single FFL correction substrate 52, which then can be micro-machined to adjust the respective focal length variations. FFL

correction substrate 52 then can be diced at the appropriate locations so that each module includes a pair of lens stacks, rather than just a single lens stack.

[0041] In some implementations, a black (i.e., non-transparent) coating can be added to the bottom (i.e., sensor-side) surface of FFL correction substrate, to the bottom surface of one or more of the FFL correction layers, and/or between adjacent FFL correction layers. FIG. 17 illustrates an example of a glass FFL correction substrate 52 that has an IR filter 90, color filters 92, and a black spacer 96 atop a black coating layer 94 for cross channel stray light reduction on the lens stack side of FFL correction substrate 52. The sensor side of substrate 52 includes a channel FFL correction layer 100 and a module FFL correction layer 102. Channel FFL correction layer 100 can provide FFL correction or adjustment that differs for the two channels (i.e., C1 and C2). Module FFL correction layer 102 can provide an additional FFL correction or other adjustment that applies equally to all the optical channels. Black coating layers 104 can be provided to help reduce stray light in the optical module. Coating techniques (e.g., spin coating, spraying and sputtering) can be used to provide black coating layers 104 and/or channel FFL correction layer 100. In a particular implementation, the thickness of the FFL correction layers is approximately as follows: 400  $\mu\text{m}$  for FFL correction substrate 52, 25  $\mu\text{m}$  for FFL correction layer 100, and 150  $\mu\text{m}$  for FFL correction layer 102.

[0042] FIGS. 18 through 29 illustrate an example fabrication process for making a sensor module that includes an array of lens stacks mounted on a FFL correction structure with various features similar to those of FIG. 17. As shown in FIG. 18, a glass or other substrate 202 serves as a first FFL correction substrate. Dashed vertical lines 204 indicate the locations of optical axes for optical channels. An IR filter layer 206 can be coated on the lens stack side of substrate 202 (i.e., the side on which the lens stacks are to be mounted). As shown in FIG. 19, the entire sensor side of FFL substrate 202 (i.e., the side on which the sensor is to be attached) is coated with a black coating 208 (i.e., a material that absorbs all or a substantial amount of light impinging on its surface or that is substantially non-transparent to a particular wavelength or range of wavelengths). Coating 208 can help reduce optical cross-talk or interference caused by stray light.

Photolithographic techniques can be used to remove portions of coating 208 to provide openings 210 in the vicinity of the optical channels as shown in FIG. 20.

[0043] As illustrated in FIG. 21, the lens stack side of FFL substrate 202 is coated with a first color filter layer 212. Next, portions of first color filter layer 212 are removed, for example, by photolithographic techniques, except on areas over selected ones of channel openings 210 (see FIG. 22). The foregoing steps are repeated for a second color filter layer 214, such that, as shown in FIG. 23 each channel opening 210 is covered by one of the first or second color filter layers 212, 214. In the illustrated example, areas above channel openings 210 are covered alternately by either the first color filter layer 212 or the second color filter layer 214. The first and second color filter layers allow selected wavelengths or wavelength ranges (e.g., red, green or blue) to pass through. In some implementations, more than two different color filters are applied. For example, in some cases, three color filters are applied so as to obtain red, green and blue channels.

[0044] As illustrated by FIG. 24, black spacers 216 (i.e., composed of a material that absorbs all or a substantial amount of light impinging on their surface or that is non-transparent to substantially all the light in a particular wavelength or range of wavelengths) are provided on the lens stack side of FFL substrate 202 between pairs of adjacent color filters 212, 214. Black spacers 216, which can be formed for example by vacuum injection techniques, can help reduce cross channel stray light. In this case, a FFL correction wafer can be placed on a vacuum chuck, and a PDMS tool with spacer sections is brought into contact with the FFL correction wafer. A vacuum is applied, and non-transparent, curable epoxy material is injected into the tool to form the spacers on the FFL correction wafer. The epoxy material can be hardened by applying UV radiation. Alternatively, embossing techniques can be used to form black spacers 216. In some implementations, additional black spacers 216A can be provided on the sides of color filter 212, 214 such that the black spacers 216A surround the color filters in a grid-like manner as shown in FIGS. 24A and 24B. The size and position of black spacers 216 may depend on the dimensions of the overlying lens stacks that are to be placed on FFL substrate 202.

[0045] As shown in FIG. 25, individual lens stacks or MxN arrays 218 of lens stacks are attached over the lens stack side of FFL substrate 202. If IR filter layer 206 is not present, then MxN arrays 218 can be attached directly to the lens stack side of FFL substrate 202. Otherwise, MxN arrays 218 can be attached to the upper surface of IR filter layer 206. If black spacers 216 surround the color filters as in FIG. 24A, then the lens stack can be mounted directly on the black spacers 216 as shown in FIG. 25A.

[0046] Next, the FFL is measured for each lens stack in MxN arrays 218. A channel FFL correction layer 220 then is attached or applied (e.g., by coating techniques such as spin coating, spraying or sputtering) to the sensor side of FFL substrate 202, as illustrated in FIG. 26. Channel FFL layer 220 can be composed, for example, of a glass material and/or polymer material. Based on the FFL measurement for each lens stack, photolithographic techniques are used to remove portions of channel FFL correction layer 220 below the various lens stacks so as to achieve desired FFL values for the lens stacks. Since the lens stacks may have different FFL values, different amounts of channel FFL correction layer 220 may be needed to achieve corrected FFL values for the various lens stacks (see FIG. 27). For some lens stacks, no FFL correction may be needed, in which case channel FFL correction layer 220 can be removed in its entirety in the areas below those particular lens stacks. In other cases, a portion of channel FFL correction layer 220 may be removed in the area below a particular lens stack. In yet other cases, no portion of channel FFL correction layer 220 may be removed below a particular lens stack. Thus, depending on the implementation, channel FFL correction layer 220 may be present for all of the lens system or only some of the lens systems. Furthermore, the thickness of the final channel FFL correction layer 220 may vary from one lens system to the next, depending on the amount of FFL correction needed for each lens system.

[0047] Next, as shown in FIG. 28, spacers 222 can be attached, for example, at the sensor side of FFL substrate 202 (e.g., to the lower surface of black coating 208), which can increase the stability of the module. In some implementations, spacers 222 are provided by a vacuum injection technique. Spacers 222 can serve as a module FFL correction

layer. The height of the spacers 222 can be adjusted separately for each module (e.g., each 2x2 array of lens stacks) to compensate for the FFL variation. Such adjustments can be performed, for example, using micromachining techniques. The individual modules can be separated, for example, by dicing along dicing lines 224.

[0048] An image sensor 226 then can be attached to the lower side of spacers 222, as shown in FIG. 29. Image sensor 226 can include, for example, multiple light emitting and/or light sensing elements aligned, respectively, with different optical channels 204 in the module. Above each lens system is a respective opening 228 that is substantially aligned with the optical axis 204 of a particular one of the lens systems and that allows light to enter or exit the module. The foregoing techniques can provide a module with one or more lens stacks having FFL values that are adjusted to achieve effective desired values using a FFL correction structure.

[0049] In some implementations, the various steps of FIGS. 18-29 may be performed in a different order. For example, it is possible to process color filters 212, 214 and black spacers 216 before applying black coating 208. It is also possible to measure the FFL of the lens stacks separately before they are attached to the FFL correction structure, and to proceed with subsequent processing steps (e.g., as in FIGS. 26, 27, 28, 30 or 31) without the lens stack attached. In some cases, some of the steps may be omitted or additional steps may be added. Depending on the implementation, coatings 206, 208, 212, 214 can be applied to the lens side or the sensor side of FFL correction substrate 202 or channel FFL correction layer 220.

[0050] Depending on the amount of FFL compensation required for a particular lens stack, multiple channel FFL correction layers 220A, 220B can be provided. An example is illustrated in FIG. 30, which shows the use of a first channel FFL correction layer for some of the lens stacks, and the use of first and second channel FFL correction layers 220A, 220B for other of the lens stacks.

[0051] Instead of using photolithographic techniques to remove portions of channel FFL correction layer 220 (see the description above in connection with FIGS. 26 and 27), micromachining techniques can be used to remove portions of channel FFL correction layer 220 (see FIG. 31). In that case, FFL correction spacers 222 for the modules can be attached to channel FFL correction layer 220 (see FIG. 31), instead of being attached to black coating 208.

[0052] In the foregoing examples, channel FFL correction layer 220 is attached at the sensor side of FFL correction substrate 202 (i.e., on the image sensor side). In some implementations, a channel FFL correction layer 220 can be attached to the lens stack side of FFL correction substrate 202. For example, as illustrated in FIG. 32, channel FFL correction layer 220 can be provided over color filter layers 212, 214 in the particular optical channels for those lens stacks requiring FFL correction. Channel FFL correction layer 220 can be added, for example, prior to mounting the lens stacks.

Photolithographic techniques can be used to form channel FFL correction layer 220. Such techniques can be particularly useful, for example, if the lens stacks display a relatively uniform and reproducible FFL variation.

[0053] As described above in connection with FIG. 28 for modules that include multiple optical channels, FFL correction layers 202 can be added, as needed, to provide FFL correction for individual channels, and spacers 222 can be added to provide FFL correction for the module as a whole. In situations where the module includes only a single optical channel (rather than multiple channels), spacers can be attached to the transparent substrate 202, and their height adjusted to provide a desired FFL correction for the optical channel. As the module includes only a single optical channel, there is no need to include separate FFL correction layers 220. An example of such a module is illustrated in FIG. 33, which shows lens stack 40 attached to a transparent cover 202 by way of a first spacer 216A. The sensor side of the transparent cover 202 is attached, by way of a second spacer 222, to an image sensor 238 that includes a light detecting element (e.g., a photodiode) 240. In this and the other implementations described above,

the spacers 216A, 222 can be, for example, ring shaped and can be formed, for example, by vacuum injection. The image sensor 238 is mounted on a substrate 242.

[0054] The single channel module of FIG. 33 can be fabricated, for example, using a wafer-level technique. As shown in FIG. 34, first spacers 352 are attached to one side of a transparent wafer 354, and second spacers 356 are attached to the second side of the transparent wafer 404. Spacer wafers can be used to provide the first and second spacers 352, 356. In some implementations, the spacers 352, 356 are formed on the transparent wafer 354 by a vacuum injection technique. The transparent wafer 354 can be composed, for example, of glass or polymer material, whereas the spacers 352, 356 can be composed, for example, of a non-transparent material. Singulated injection molded lens stacks 40 are attached to the first spacers 352. The FFL of each lens stack 40 then is measured and, if needed, the height of the spacers 356 where the lens stack 40 is attached can be adjusted to provide FFL correction for the optical channel. The height of the spacers 356 can be adjusted, for example, by micromachining or other techniques. The sensor side spacer wafer 356 then is attached to respective image sensors 238 mounted on a substrate wafer (e.g., a printed circuit board wafer) 358. The resulting stack can be separated (e.g., by dicing) to obtain single channel modules.

[0055] In the foregoing examples, mounting the lens stacks on the FFL correction substrate preferably is performed by placing individual (i.e., singulated) lens stacks onto the FFL correction substrate. However, in some implementations, instead of placing singulated lens stacks on the FFL correction substrate, a stack 302 of transparent optics wafers 304, each of which has multiple lenses 306, can be placed on a FFL correction substrate 308 (see FIG. 35). The stack 302 of optics wafers 304 can include non-transparent spacers 310A, 310B that separate the optics wafers 304 from one another and from the FFL correction substrate 308.

[0056] The spacer/optics stack 302 can be attached to the FFL correction substrate 308 using, for example, a thermally stable adhesive. In order to prevent stray light, openings such as trenches 312 are formed between the lens stacks and subsequently are filled with

non-transparent material (see FIG. 36). Trenches 312 should extend entirely through the thickness of both wafers 304 and, preferably, should extend at least partially into lower spacers 310B. In some cases, the trenches 312 can extend to the upper surface of the FFL correction substrate 308. Trenches 312 can be formed, for example, by dicing, micromachining or laser cutting techniques. As explained below, trenches 312 subsequently can be filled with a non-transparent material so as to provide a non-transparent layer on the sidewalls of the various portions of the transparent wafers 304.

[0057] As shown in FIG. 37, a vacuum injection PDMS tool 314 is placed over the spacer/optics stack 302 to facilitate filling trenches 312 with a non-transparent material (e.g., epoxy with carbon black). A vacuum chuck 316 is provided below and around the spacer/optics stack 302 so as to apply a vacuum between the vacuum injection tool 314 and the FFL correction substrate 308. The non-transparent material can be injected into an inlet 318 in the vacuum chuck 316. A vacuum pump 320 near an outlet of the vacuum chuck 316 facilitates flow of the injected non-transparent material. Examples of the non-transparent material include UV- or thermally-curing epoxies (or other polymers) containing carbon black (or another dark pigment) or an inorganic filler or a dye. In some implementations, the additive is embedded in the epoxy (or other polymer).

[0058] After filling trenches 312 with the non-transparent material under vacuum, the material is hardened (e.g., by UV or thermal curing), and the tool 314 is removed from the spacer/optics stack 302. The result, as shown in FIG. 38, is that non-transparent regions 322 (e.g., epoxy with carbon black) are formed between adjacent portions of the transparent optics wafers 304. The top portion of the non-transparent regions 322 can be substantially flush with the exterior surface of the various portions of the transparent optics wafers 304 and can be composed of the same non-transparent material or a different non-transparent material as spacers 310A, 310B. In some implementations, a baffle wafer composed of a non-transparent material is attached over the optics/spacer stack 302. In other implementations, the baffle wafer can be omitted.

[0059] After forming the non-transparent regions 322 and removing the vacuum injection tool 314, the FFL correction substrate 308 can be processed as described above. Thus, for example, a method of fabricating optical devices can include attaching, over a transparent FFL correction substrate, an optics/spacer stack that includes a plurality of lens systems. In some cases, openings such as trenches are formed through portions of the optics/spacer stack that separate the lens systems from one another, and the openings then are filled with a non-transparent material. The thickness of the substrate can be adjusted below at least some of the lens systems to provide respective focal length corrections for the lens systems. Adjusting the thickness of the substrate may include removing selected portions of the FFL correction substrate or adding one or more layers below at least some of the lens systems so as to correct for variations in the focal lengths of the lens systems. Subsequently, the FFL correction substrate can be separated into a plurality of optical modules, each of which includes one or more of the lens systems mounted over a portion of the FFL correction substrate. The sides of the resulting modules, including the sides of the transparent substrates on which the lenses are formed, are covered by non-transparent material, which can help reduce stray light from entering the modules.

[0060] Other implementations are within the scope of the claims.

What is claimed is:

1. A method of fabricating optical devices, the method comprising:  
mounting a plurality of singulated lens systems over a substrate;  
adjusting a thickness of the substrate below at least some of the lens systems to provide respective focal length corrections for the lens systems; and  
subsequently separating the substrate into a plurality of optical modules, each of which includes one of the lens systems mounted over a portion of the substrate.
2. The method of claim 1 wherein adjusting a thickness of the substrate includes using micro-machining to form respective holes below at least some of the lens systems so as to correct for variations in the focal lengths of the lens systems.
3. The method of claim 1 wherein adjusting a thickness of the substrate includes adding one or more layers below at least some of the lens systems so as to correct for variations in the focal lengths of the lens systems.
4. The method of claim 1 wherein each of the lens systems includes a lens stack.
5. The method of claim 1 wherein the substrate includes a plurality of layers of different materials.
6. The method of claim 5 wherein adjusting a thickness of the substrate includes forming respective holes in a layer of the substrate that is furthest from the lens systems.
7. The method of claim 1 including fabricating the lens systems in a wafer-level process and separating a wafer-stack to form the plurality of singulated lens systems before mounting the singulated lens systems on the substrate.
8. The method of claim 1 including at least partially filling gaps between adjacent lens systems with a non-transparent material so that each lens system is surrounded by non-transparent walls.

9. The method of claim 1 wherein the substrate is composed of a material that is substantially transparent to light of a predetermined wavelength or range of wavelengths.

10. The method of claim 9 wherein the substrate is composed of one or more glass or polymer materials.

11. The method of claim 1 wherein a surface of the substrate includes one or more optical filter layers, the method including mounting the lens systems at positions where the one or more optical filters are located.

12. A method of fabricating optical devices, the method comprising:  
    placing a plurality of individual lens stacks on a substrate;  
    micro-machining the substrate at positions below one or more of the lens stacks to adjust focal lengths for at least some of the lens stacks; and  
    subsequently dicing the substrate into a plurality of optical modules, each of which includes one or more of the lens stacks on respective portions of the substrate.

13. The method of claim 12 including:  
    providing a cross channel stray light reduction element on the substrate between adjacent ones of the lens stacks, and  
    dicing the substrate into a plurality of optical modules, each of which includes two of the lens stacks separated by the cross channel stray light reduction element.

14. The method of claim 13 wherein the cross channel stray light reduction element includes a black spacer atop a black coating layer.

15. The method of claim 12 wherein a surface of the substrate includes one or more optical filter layers, the method including mounting the lens systems on the one or more optical filters.

16. The method of claim 15 wherein the one or more optical filters include a color filter.

17. The method of claim 15 wherein the one or more optical filters include an infra-red filter.

18. The method of claim 15 including dicing the substrate into a plurality of optical modules, each of which includes two of the lens stacks each of which is mounted on a filter having different optical properties.

19. The method of claim 12 including dicing the substrate into a plurality of optical modules, each of which includes two of the lens stacks, wherein an amount of micro-machining of the substrate below each of the lens stacks in the module differs from one another.

20. The method of claim 12 wherein the substrate includes a plurality of layers of different materials.

21. The method of claim 20 including providing a black coating to a bottom surface of the substrate, to a bottom surface of one or more of the layers of the substrate, and/or between adjacent layers of the substrate.

22. An apparatus comprising:

a substrate having a thickness that varies from one area of the substrate to another area;

a plurality of singulated optical systems mounted over the substrate, wherein respective ones of the optical systems are disposed over different areas of the substrate so as to provide focal length corrections to at least some of the optical systems.

23. The apparatus of claim 22 wherein corrected focal lengths of all the optical systems mounted over the substrate are substantially the same as one another.

24. The apparatus of claim 22 wherein each of the optical systems includes a lens stack.

25. The apparatus of claim 22 wherein the substrate includes a plurality of layers of different materials.

26. The apparatus of claim 25 including a black coating on the first surface of the substrate, on a surface of one or more of the layers of the substrate, and/or between adjacent layers of the substrate.

27. The apparatus of claim 22 including a cross channel stray light reduction element on the substrate between adjacent ones of the lens stacks.

28. The apparatus of claim 27 wherein the cross channel stray light reduction element includes a black spacer atop a black coating layer.

29. The apparatus of claim 27 wherein adjacent optical modules are mounted on respective filters having different optical properties from one another.

30. The apparatus of claim 22 wherein the second surface of the substrate includes one or more optical filter layers, and wherein the optical systems are mounted on the one or more optical filters.

31. The apparatus of claim 30 wherein the one or more optical filters include a color filter.

32. The apparatus of claim 30 wherein the one or more optical filters include an infra-red filter.

33. A method of fabricating optical devices, the method comprising:  
attaching a plurality of lens systems to a first side of a substrate composed of a material that is substantially transparent to light of a predetermined wavelength or range of wavelengths;  
providing a channel FFL correction layer on a second side of the substrate; and  
removing selected portions of the channel FFL correction layer so as to adjust respective focal length variations for at least some of the lens systems.
34. The method of claim 33 wherein the selected portions of the channel FFL correction layer are removed by a photolithographic technique.
35. The method of claim 33 wherein the selected portions of the channel FFL correction layer are removed by micromachining.
36. The method of claim 33 further including:  
measuring a respective focal length for each lens system; and  
removing respective amounts of the channel FFL correction layer at different locations based on the measured focal lengths for the lens systems.
37. The method of claim 33 including dicing the substrate to form a plurality of modules each of which includes a plurality of lens stacks.
38. The method of claim 33 including dicing the substrate to form a plurality of modules each of which includes a plurality of lens stacks, wherein each lens stack has an optical axis intersected by a respective color filter layer.
39. The method of claim 33 further including:  
attaching spacers at the second side of the substrate; and  
adjusting respective heights of at least some of the spacers to compensate for FFL variations of the lens systems.

40. An optical module comprising:

a substrate composed of a material that is transparent to light of a particular wavelength of range of wavelengths;

a plurality of lens systems attached over a first side of the substrate, wherein each lens system has a respective optical axis that intersects the substrate and corresponds to a respective optical channel in the module;

a plurality of color filter layers disposed over different regions of the substrate, wherein the optical axis of each lens system intersects a respective one of the color filter layers;

a spacer disposed over the substrate between a respective pair of the color filter layers, wherein the spacer is substantially non-transparent to light of the particular wavelength of range of wavelengths;

a channel FFL correction layer, wherein the optical axis of at least one of the lens systems intersects the channel FFL correction layer; and

an image sensor attached over a second side of the substrate.

41. The optical module of claim 40 wherein the channel FFL correction layer is composed of a glass or polymer material.

42. The optical module of claim 40 wherein the optical axes of fewer than all of the lens systems intersect the channel FFL correction layer.

43. The optical module of claim 40 wherein the optical axes of a plurality of the lens systems intersect the channel FFL correction layer, and wherein respective portions of the channel FFL correction layer intersected by the optical axes have different thicknesses from one another.

44. The optical module of claim 40 wherein the channel FFL correction layer is disposed over the second side of the substrate.

45. The optical module of claim 40 wherein the channel FFL correction layer is disposed over the first side of the substrate.
46. The optical module of claim 40 further including a IR filter layer over the first side of the substrate.
47. The optical module of claim 46 wherein the plurality of color filter layers are disposed on the IR filter layer.
48. The optical module of claim 40 comprising first and second color filter layers each of which allows different wavelength or range of wavelengths to pass through, wherein the optical axis of a first one of the lens systems intersects the first color filter layer and the optical axis of a second one of the lens systems intersects the second color filter layer.
49. The optical module of claim 40 further including a coating on the second side of the substrate, wherein the coating is substantially non-transparent to light of the particular wavelength of range of wavelengths and is disposed between a pair of the optical channels.
50. The optical module of claim 40 further including spacers separating the second side of the substrate from the image sensor.
51. A method of fabricating optical devices, the method comprising:  
mounting a plurality of singulated lens systems on a substrate;  
forming a respective hole in the substrate below at least some of the lens systems to provide respective focal length adjustments for the lens systems; and  
subsequently separating the substrate into a plurality of optical modules, each of which includes one of the lens systems mounted on a portion of the substrate.
52. An apparatus comprising:  
a substrate having holes in a first one of its surfaces;

a plurality of singulated optical systems mounted on the substrate on a second one of its surfaces, the second surface being on an opposite side of the substrate from the first surface, wherein respective ones of the optical systems are disposed on areas of the substrate above each of the holes so as to provide adjustments to focal lengths of the optical systems.

## AMENDED CLAIMS

received by the International Bureau on 26 February 2014 (26.02.2014)

What is claimed is:

1. A method of fabricating optical devices, the method comprising:  
mounting a plurality of singulated lens systems over a substrate;  
adjusting a thickness of the substrate below at least some of the lens systems to provide respective focal length corrections for the lens systems; and  
subsequently separating the substrate into a plurality of optical modules, each of which includes one of the lens systems mounted over a portion of the substrate.
2. The method of claim 1 wherein adjusting a thickness of the substrate includes using micro-machining to form respective holes below at least some of the lens systems so as to correct for variations in the focal lengths of the lens systems.
3. The method of claim 1 wherein adjusting a thickness of the substrate includes adding one or more layers below at least some of the lens systems so as to correct for variations in the focal lengths of the lens systems.
4. The method of claim 1 wherein each of the lens systems includes a lens stack.
5. The method of claim 1 wherein the substrate includes a plurality of layers of different materials.
6. The method of claim 5 wherein adjusting a thickness of the substrate includes forming respective holes in a layer of the substrate that is furthest from the lens systems.
7. The method of claim 1 including fabricating the lens systems in a wafer-level process and separating a wafer-stack to form the plurality of singulated lens systems before mounting the singulated lens systems on the substrate.
8. The method of claim 1 including at least partially filling gaps between adjacent lens systems with a non-transparent material so that each lens system is surrounded by non-transparent walls.

9. The method of claim 1 wherein the substrate is composed of a material that is substantially transparent to light of a predetermined wavelength or range of wavelengths.
10. The method of claim 9 wherein the substrate is composed of one or more glass or polymer materials.
11. The method of claim 1 wherein a surface of the substrate includes one or more optical filter layers, the method including mounting the lens systems at positions where the one or more optical filters are located.
12. A method of fabricating optical devices, the method comprising:  
placing a plurality of individual lens stacks on a substrate;  
micro-machining the substrate at positions below one or more of the lens stacks to adjust focal lengths for at least some of the lens stacks; and  
subsequently dicing the substrate into a plurality of optical modules, each of which includes one or more of the lens stacks on respective portions of the substrate.
13. The method of claim 12 including:  
providing a cross channel stray light reduction element on the substrate between adjacent ones of the lens stacks, and  
dicing the substrate into a plurality of optical modules, each of which includes two of the lens stacks separated by the cross channel stray light reduction element.
14. The method of claim 13 wherein the cross channel stray light reduction element includes a black spacer atop a black coating layer.
15. The method of claim 12 wherein a surface of the substrate includes one or more optical filter layers, the method including mounting the lens systems on the one or more optical filters.

16. The method of claim 15 wherein the one or more optical filters include a color filter.
17. The method of claim 15 wherein the one or more optical filters include an infra-red filter.
18. The method of claim 15 including dicing the substrate into a plurality of optical modules, each of which includes two of the lens stacks each of which is mounted on a filter having different optical properties.
19. The method of claim 12 including dicing the substrate into a plurality of optical modules, each of which includes two of the lens stacks, wherein an amount of micro-machining of the substrate below each of the lens stacks in the module differs from one another.
20. The method of claim 12 wherein the substrate includes a plurality of layers of different materials.
21. The method of claim 20 including providing a black coating to a bottom surface of the substrate, to a bottom surface of one or more of the layers of the substrate, and/or between adjacent layers of the substrate.
22. An apparatus comprising:  
a substrate having a thickness that varies from one area of the substrate to another area;  
a plurality of singulated optical systems mounted over the substrate, wherein respective ones of the optical systems are disposed over different areas of the substrate so as to provide focal length corrections to at least some of the optical systems.
23. The apparatus of claim 22 wherein corrected focal lengths of all the optical systems mounted over the substrate are substantially the same as one another.

24. The apparatus of claim 22 wherein each of the optical systems includes a lens stack.
25. The apparatus of claim 22 wherein the substrate includes a plurality of layers of different materials.
26. The apparatus of claim 25 including a black coating on the first surface of the substrate, on a surface of one or more of the layers of the substrate, and/or between adjacent layers of the substrate.
27. The apparatus of claim 22 including a cross channel stray light reduction element on the substrate between adjacent ones of the lens stacks.
28. The apparatus of claim 27 wherein the cross channel stray light reduction element includes a black spacer atop a black coating layer.
29. The apparatus of claim 27 wherein adjacent optical modules are mounted on respective filters having different optical properties from one another.
30. The apparatus of claim 22 wherein the second surface of the substrate includes one or more optical filter layers, and wherein the optical systems are mounted on the one or more optical filters.
31. The apparatus of claim 30 wherein the one or more optical filters include a color filter.
32. The apparatus of claim 30 wherein the one or more optical filters include an infra-red filter.

33. A method of fabricating optical devices, the method comprising:  
attaching a plurality of lens systems to a first side of a substrate composed of a material that is substantially transparent to light of a predetermined wavelength or range of wavelengths;  
providing a channel FFL correction layer on a second side of the substrate; and  
removing selected portions of the channel FFL correction layer so as to adjust respective focal length variations for at least some of the lens systems.
34. The method of claim 33 wherein the selected portions of the channel FFL correction layer are removed by a photolithographic technique.
35. The method of claim 33 wherein the selected portions of the channel FFL correction layer are removed by micromachining.
36. The method of claim 33 further including:  
measuring a respective focal length for each lens system; and  
removing respective amounts of the channel FFL correction layer at different locations based on the measured focal lengths for the lens systems.
37. The method of claim 33 including dicing the substrate to form a plurality of modules each of which includes a plurality of lens stacks.
38. The method of claim 33 including dicing the substrate to form a plurality of modules each of which includes a plurality of lens stacks, wherein each lens stack has an optical axis intersected by a respective color filter layer.
39. The method of claim 33 further including:  
attaching spacers at the second side of the substrate; and  
adjusting respective heights of at least some of the spacers to compensate for FFL variations of the lens systems.

40. An optical module comprising:
- a substrate composed of a material that is transparent to light of a particular wavelength or range of wavelengths;
  - a plurality of lens systems attached over a first side of the substrate, wherein each lens system has a respective optical axis that intersects the substrate and corresponds to a respective optical channel in the module;
  - a plurality of optical filters each of which intersects a respective one of the optical axes;
  - a spacer disposed over the substrate, wherein the spacer is substantially non-transparent to light of the particular wavelength of range of wavelengths;
  - a channel FFL correction layer, wherein the optical axis of at least one of the lens systems intersects the channel FFL correction layer; and
  - an image sensor attached over a second side of the substrate.
41. The optical module of claim 40 wherein the channel FFL correction layer is composed of a glass or polymer material.
42. The optical module of claim 40 wherein the optical axes of fewer than all of the lens systems intersect the channel FFL correction layer.
43. The optical module of claim 40 wherein the optical axes of a plurality of the lens systems intersect the channel FFL correction layer, and wherein respective portions of the channel FFL correction layer intersected by the optical axes have different thicknesses from one another.
44. The optical module of claim 40 wherein the channel FFL correction layer is disposed over the second side of the substrate.
45. The optical module of claim 40 wherein the channel FFL correction layer is disposed over the first side of the substrate.

46. The optical module of claim 40 further including a IR filter layer over the first side of the substrate.

47. The optical module of claim 46 wherein the plurality of color filter layers are disposed on the IR filter layer.

48. The optical module of claim 40 comprising first and second color filter layers each of which allows different wavelength or range of wavelengths to pass through, wherein the optical axis of a first one of the lens systems intersects the first color filter layer and the optical axis of a second one of the lens systems intersects the second color filter layer.

49. The optical module of claim 40 further including a coating on the second side of the substrate, wherein the coating is substantially non-transparent to light of the particular wavelength of range of wavelengths and is disposed between a pair of the optical channels.

50. The optical module of claim 40 further including spacers separating the second side of the substrate from the image sensor.

51. A method of fabricating optical devices, the method comprising:  
mounting a plurality of singulated lens systems on a substrate;  
forming a respective hole in the substrate below at least some of the lens systems to provide respective focal length adjustments for the lens systems; and  
subsequently separating the substrate into a plurality of optical modules, each of which includes one of the lens systems mounted on a portion of the substrate.

52. An apparatus comprising:  
a substrate having holes in a first one of its surfaces;  
a plurality of singulated optical systems mounted on the substrate on a second one of its surfaces, the second surface being on an opposite side of the substrate from the first surface, wherein respective ones of the optical systems are disposed on areas of the substrate above each of the holes so as to provide adjustments to focal lengths of the optical systems.

- 53. The optical module of claim 40 wherein the optical filters include an IR filter.
- 54. The optical module of claim 40 wherein the plurality of optical filters includes a color filter.
- 55. The optical module of claim 40 wherein the plurality of optical filters includes a plurality of color filters for different colors.
- 56. The optical module of claim 40 wherein the plurality of optical filters includes IR filters and color filters.

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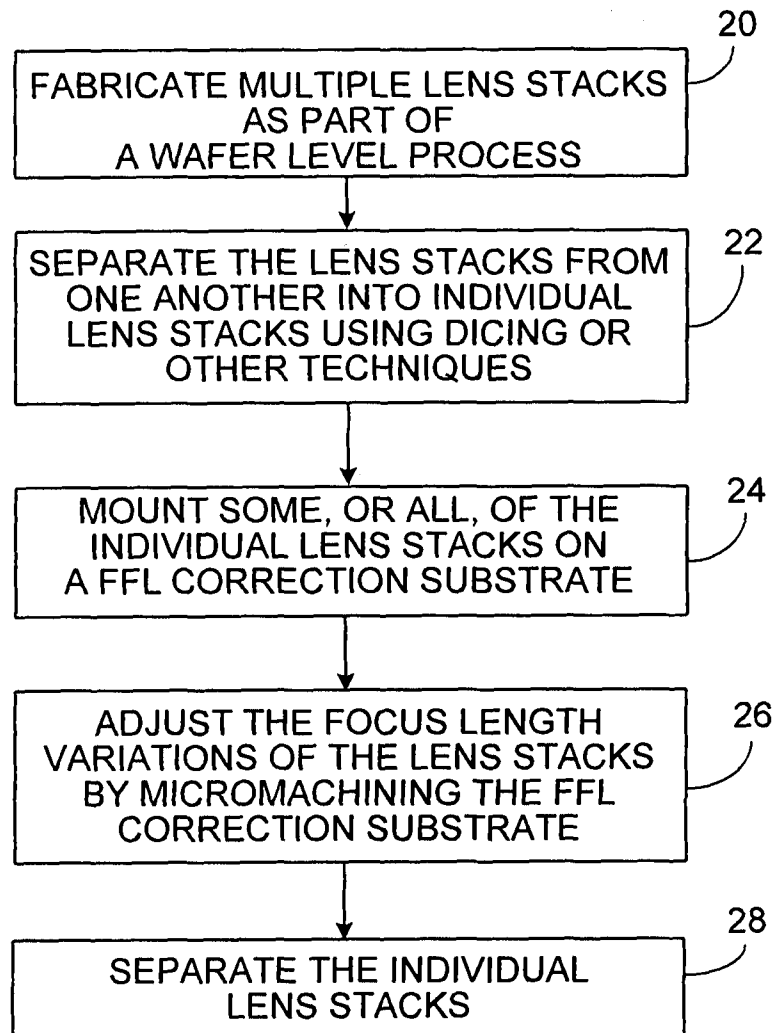


FIG. 1

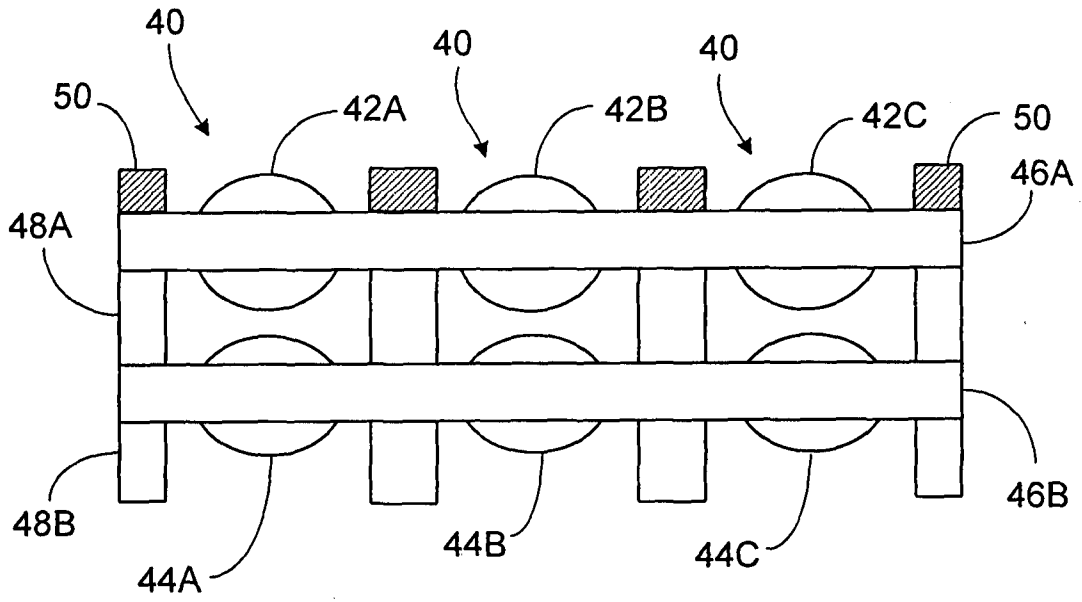


FIG. 2

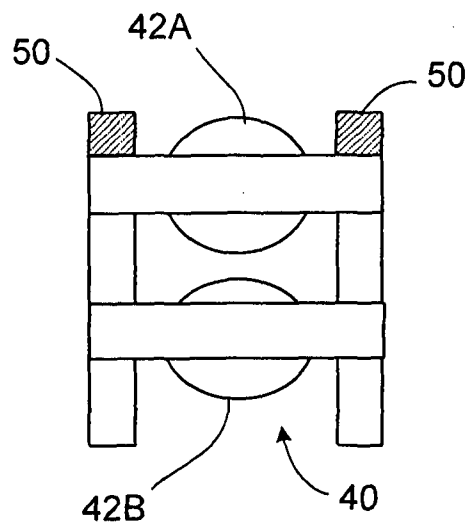


FIG. 3

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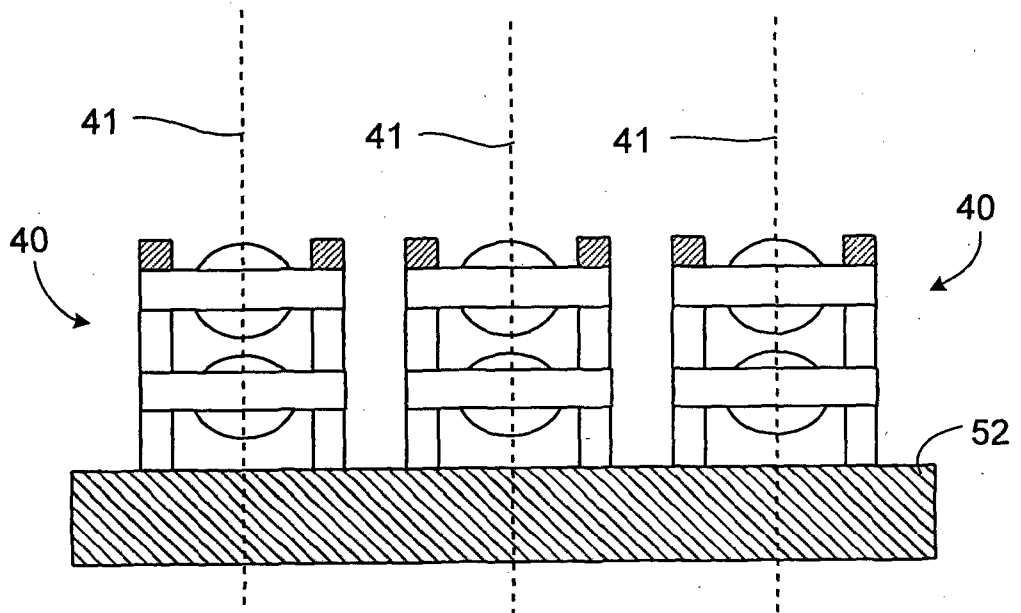


FIG. 4

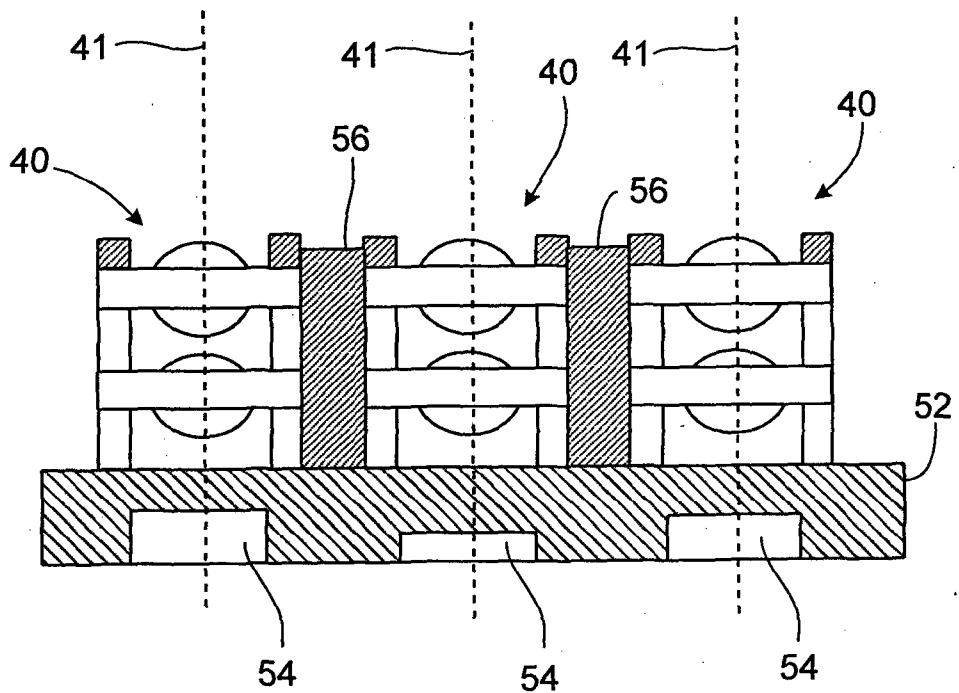
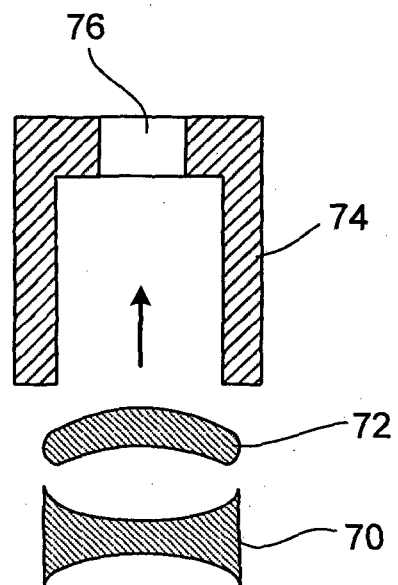
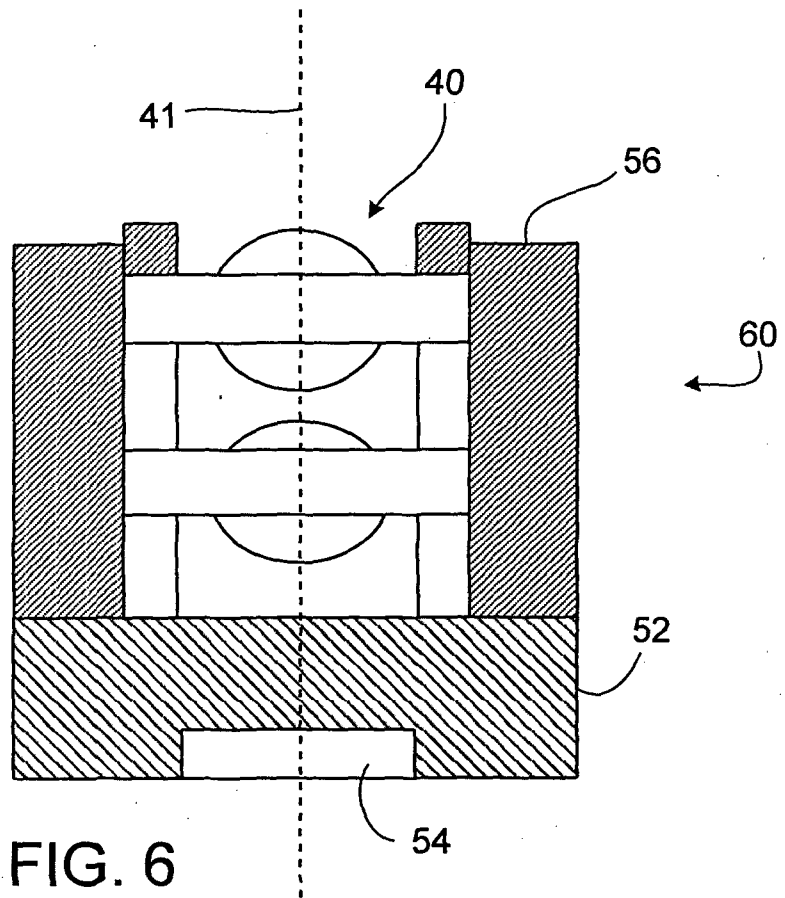


FIG. 5

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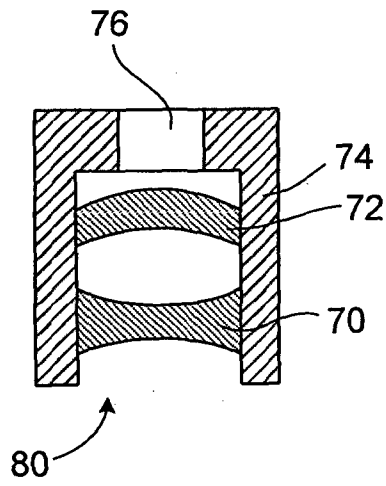


FIG. 8

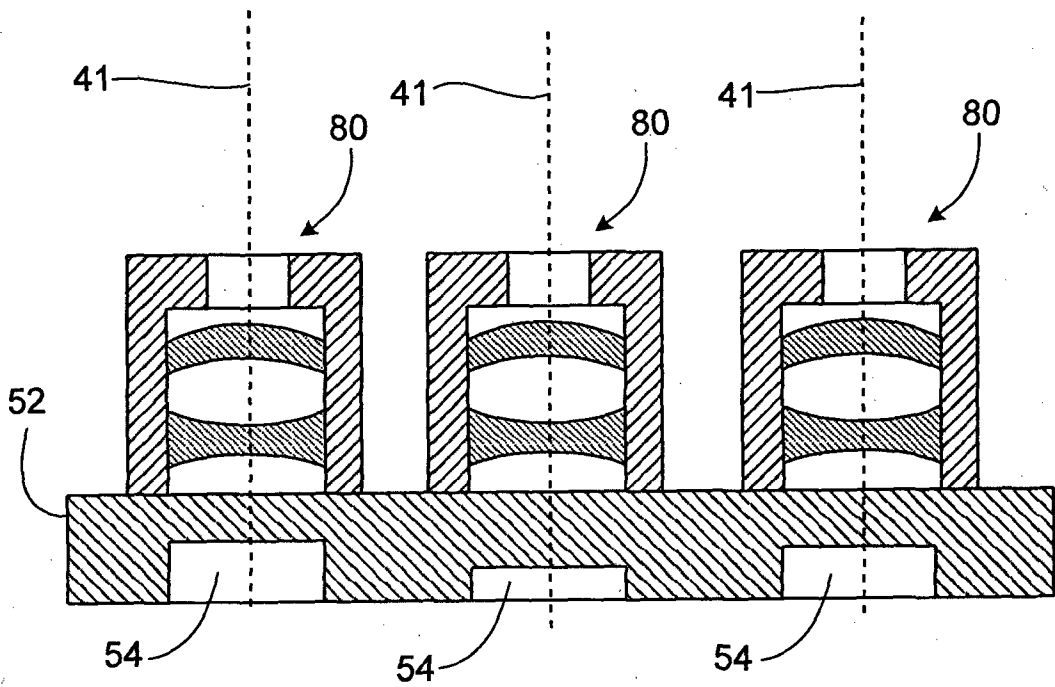


FIG. 9

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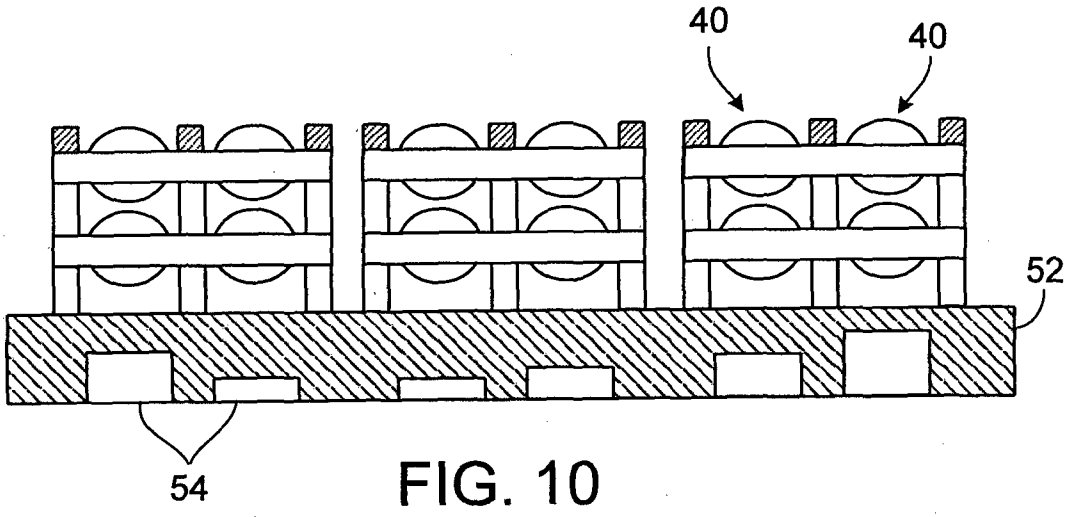


FIG. 10

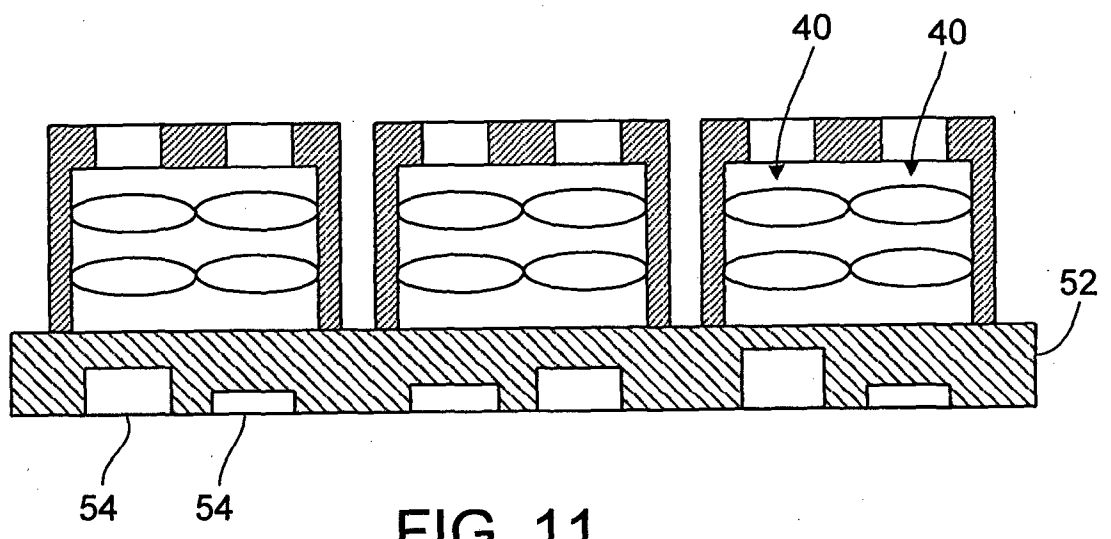


FIG. 11

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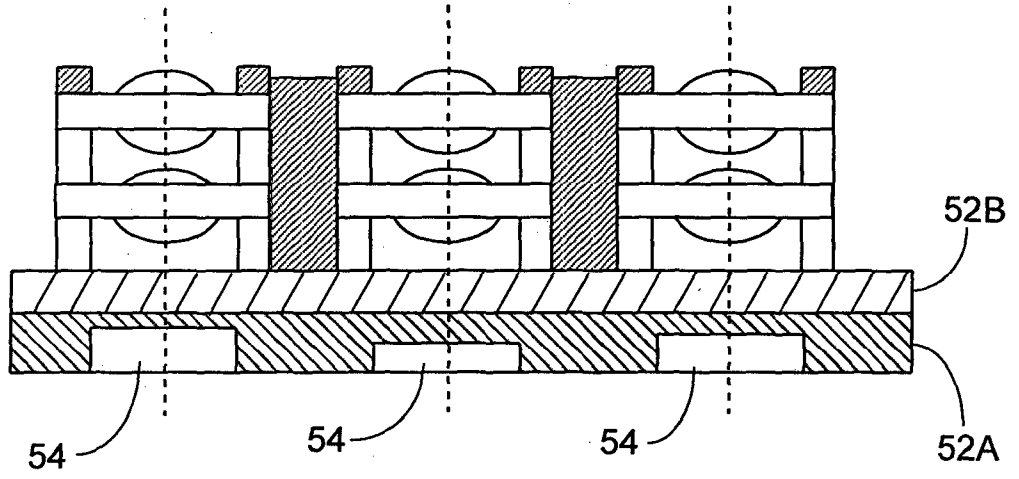


FIG. 12

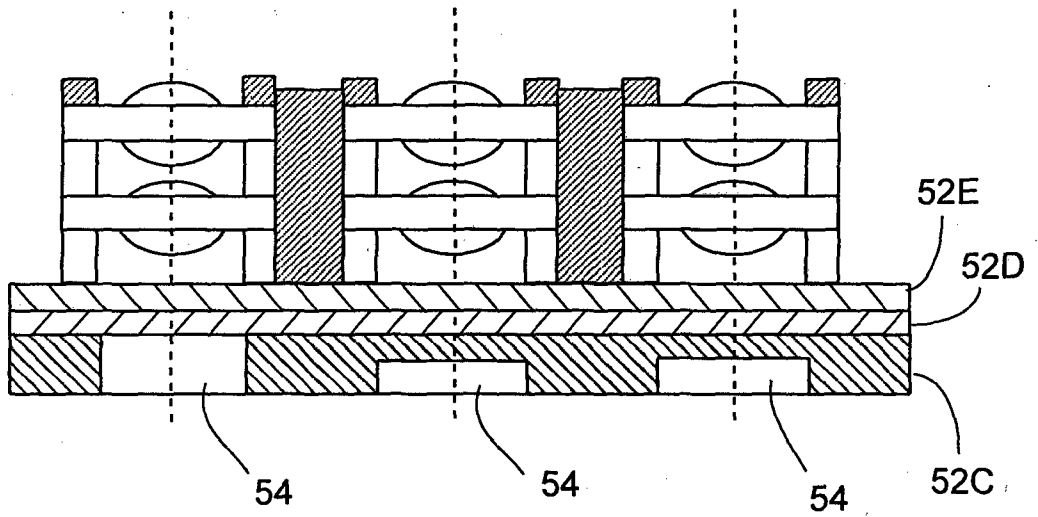


FIG. 13

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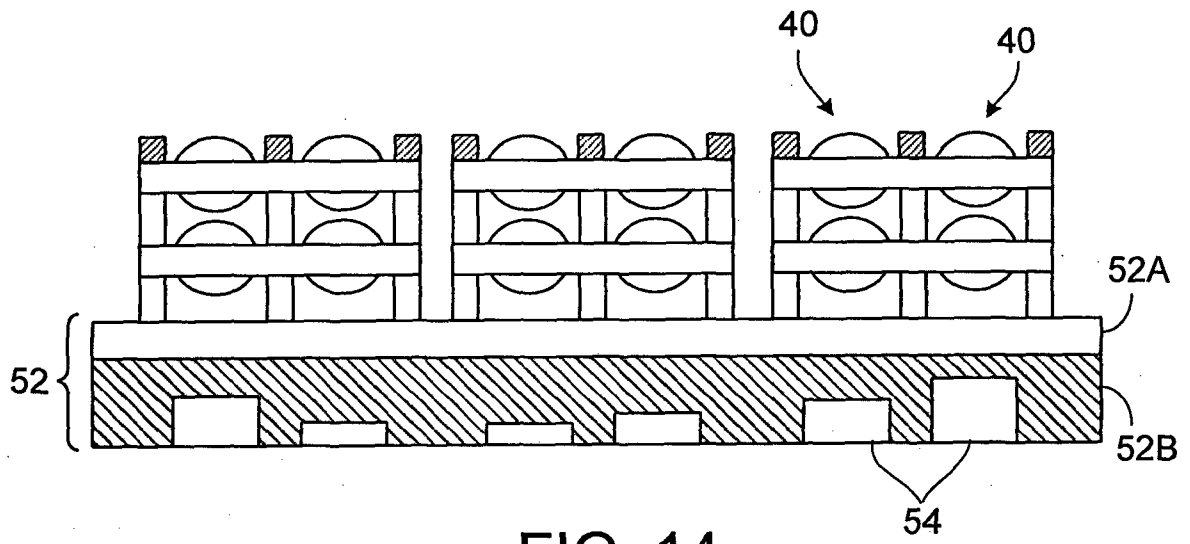


FIG. 14

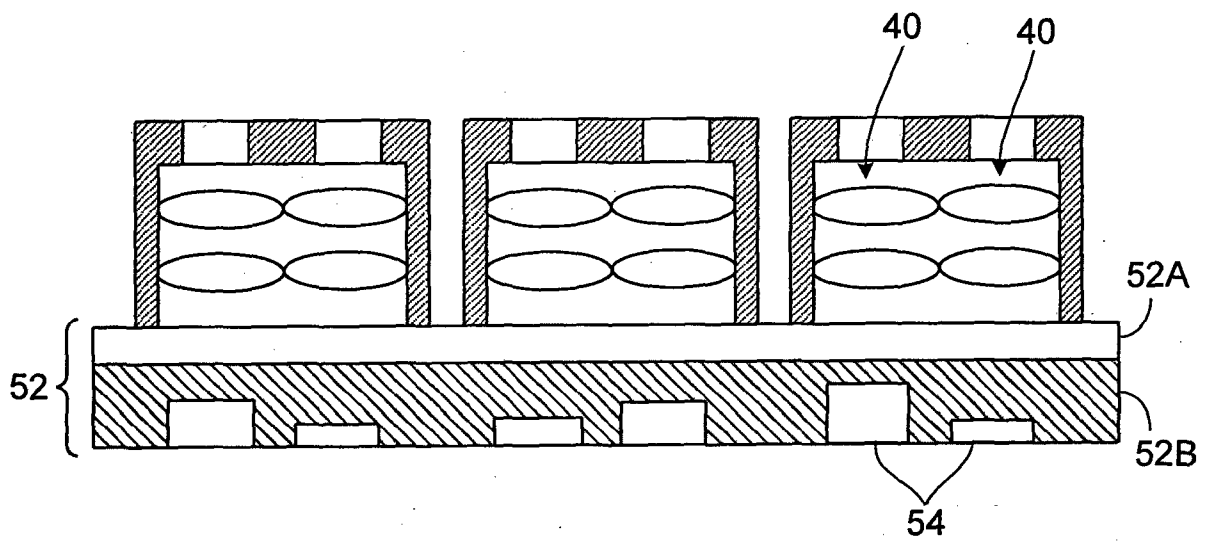


FIG. 15

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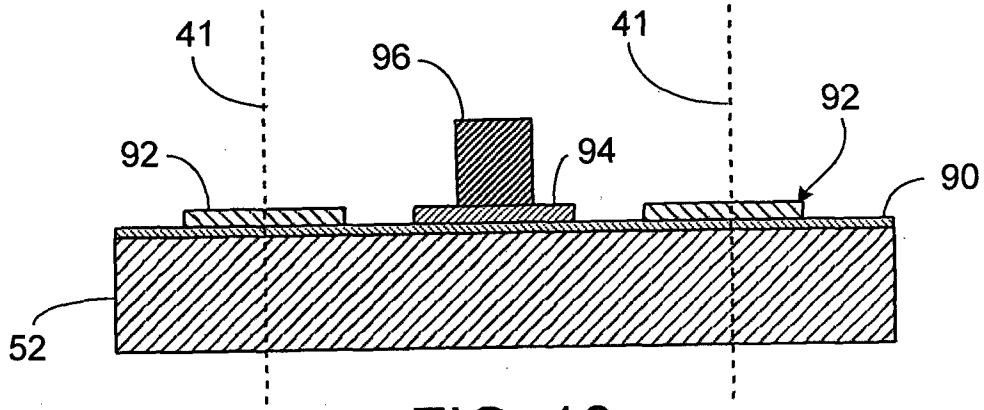


FIG. 16

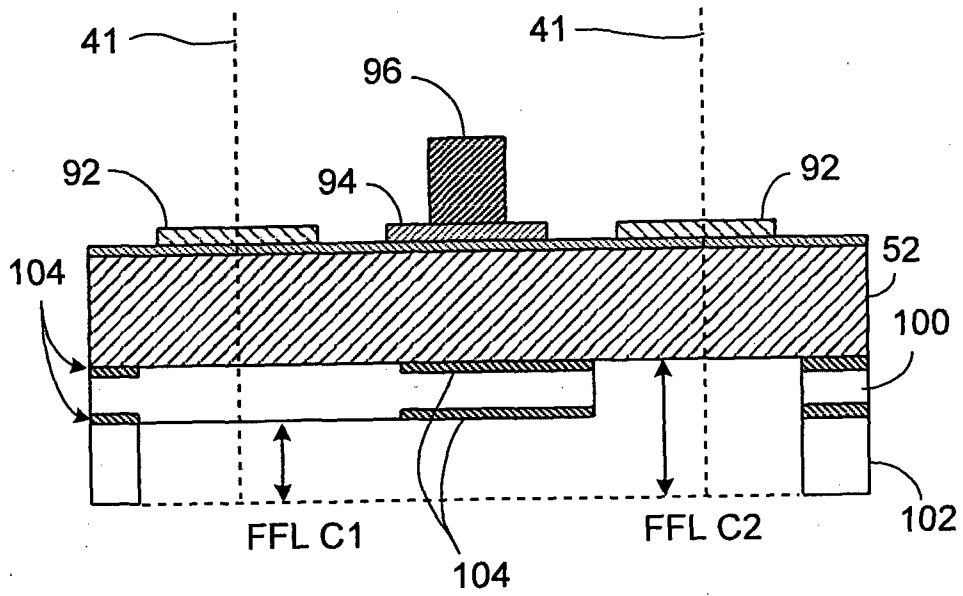


FIG. 17

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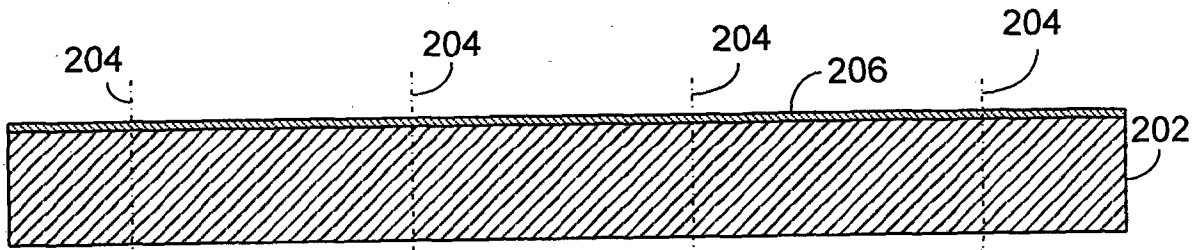


FIG. 18

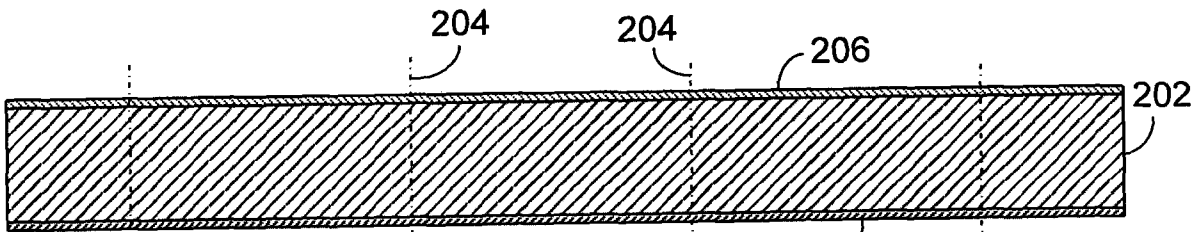


FIG. 19

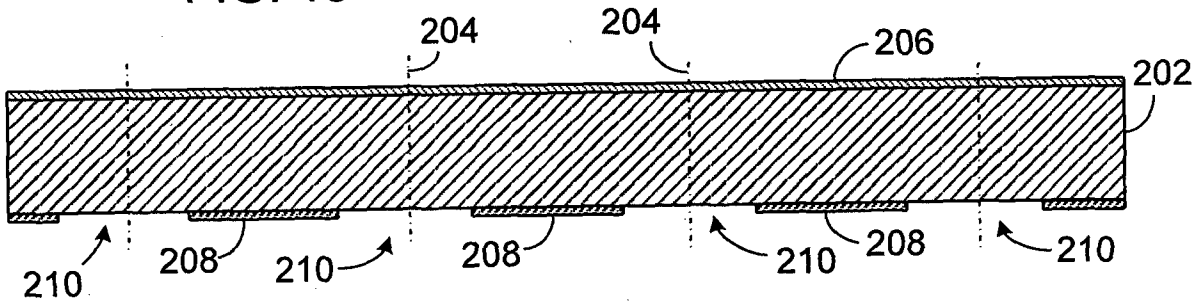


FIG. 20

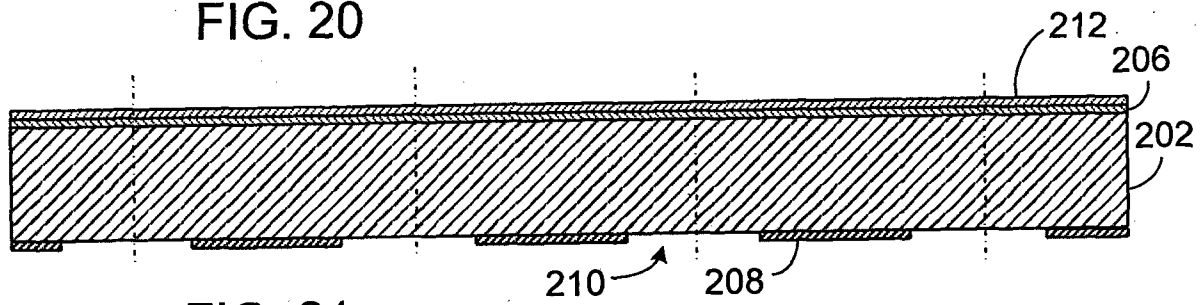


FIG. 21

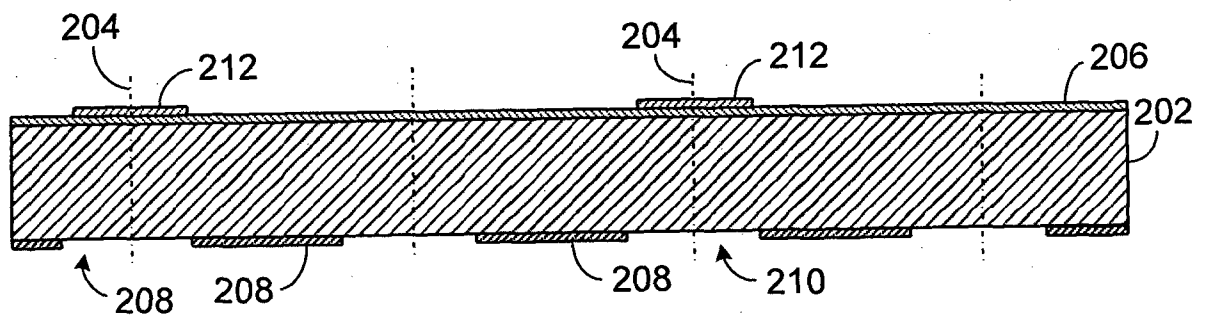


FIG. 22

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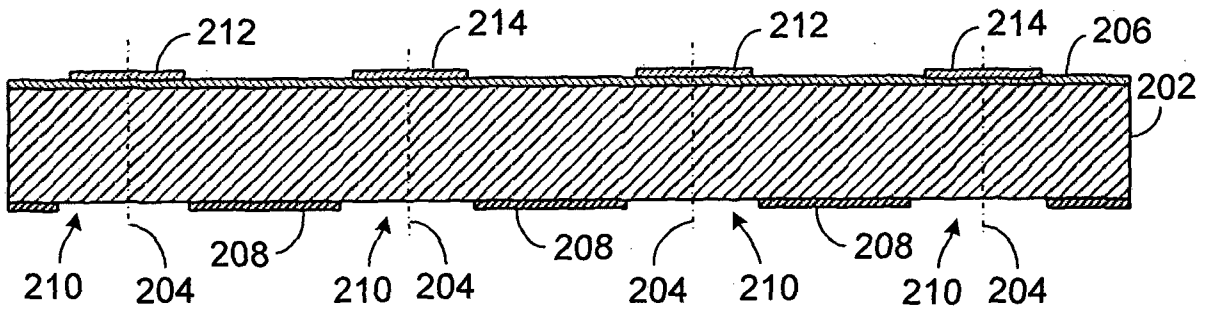


FIG. 23

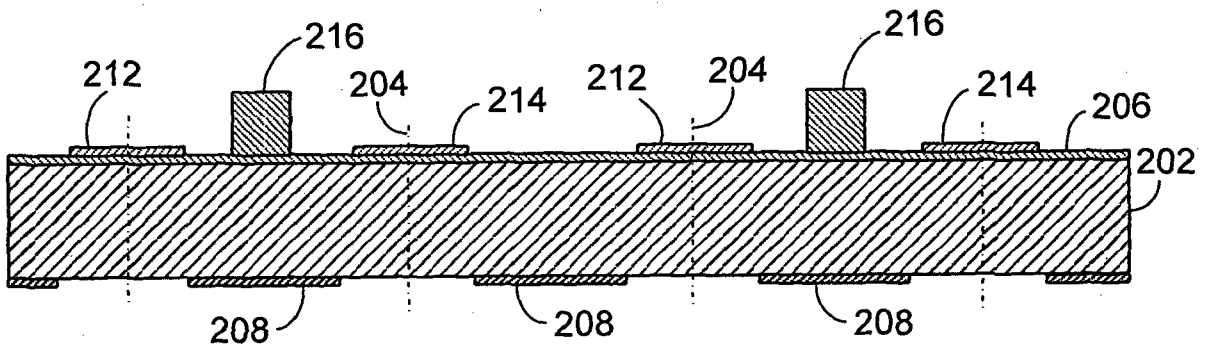


FIG. 24

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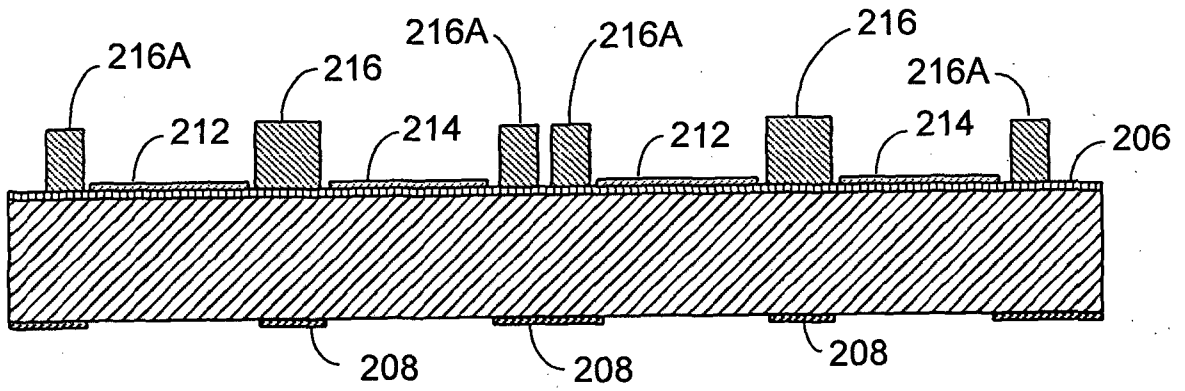


FIG. 24A

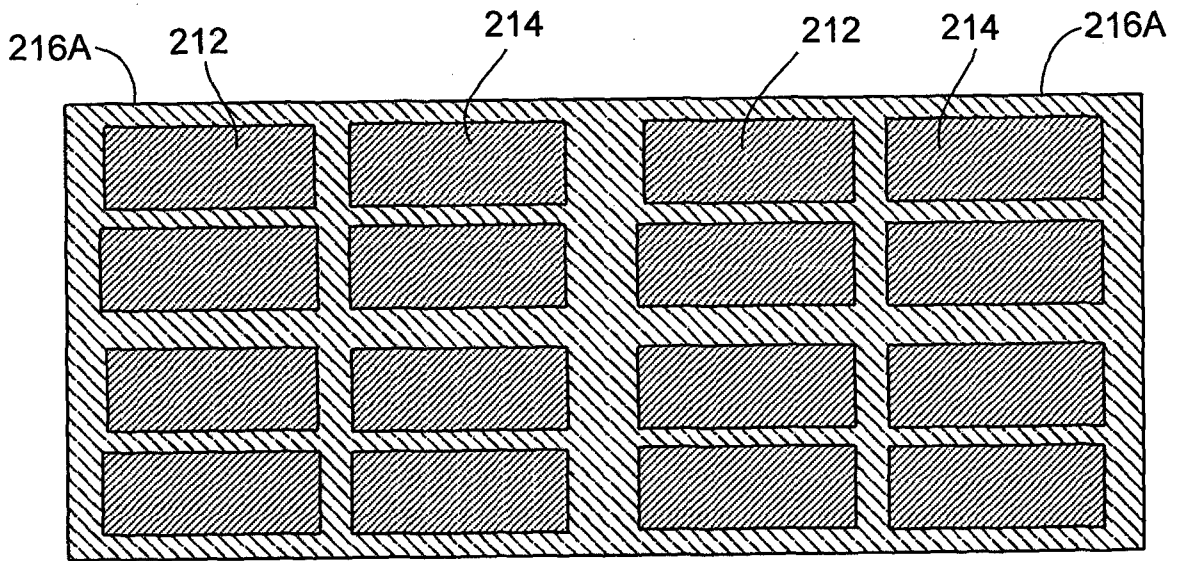


FIG. 24B

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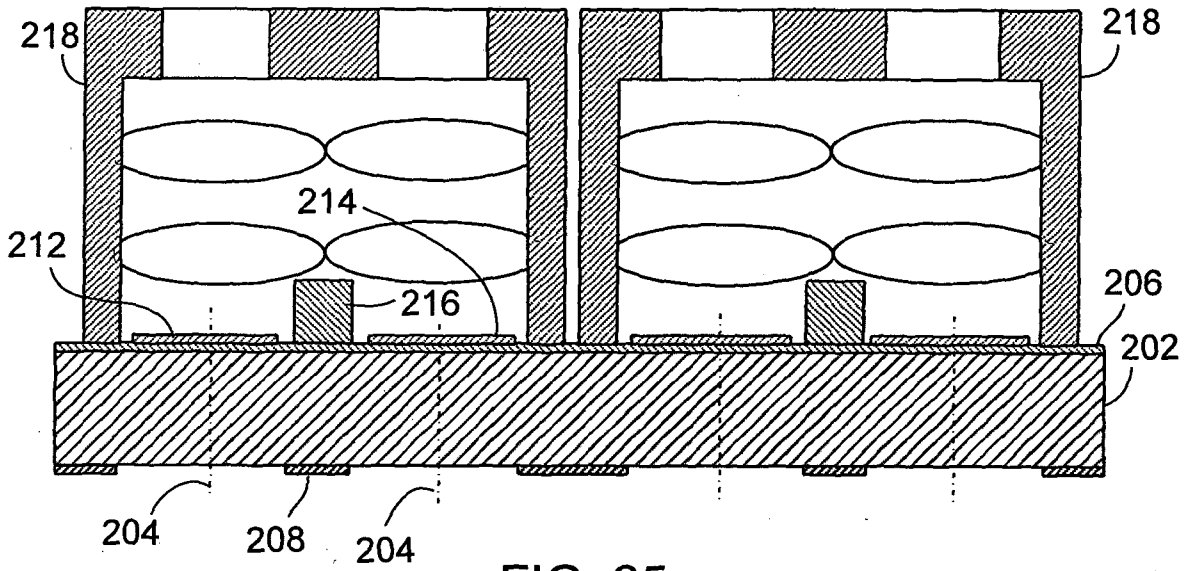


FIG. 25

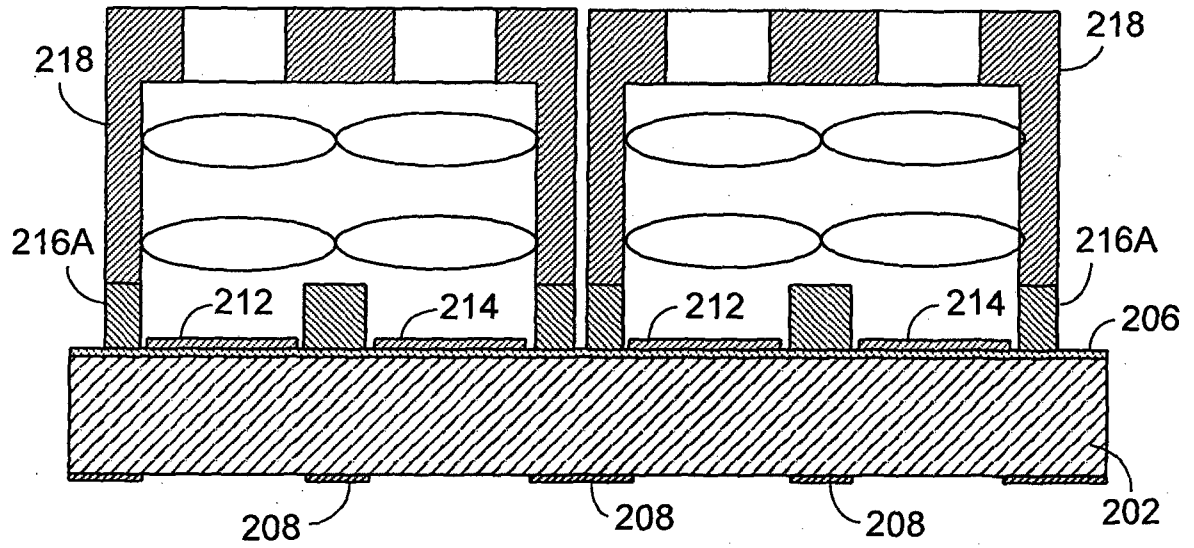


FIG. 25A

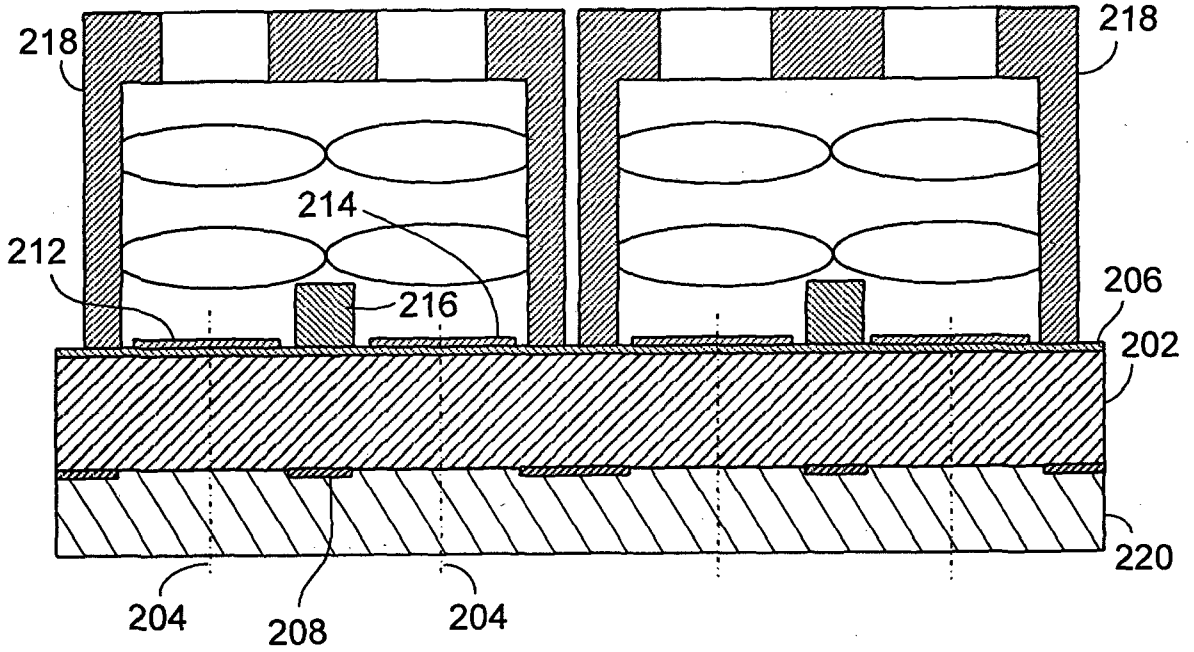


FIG. 26

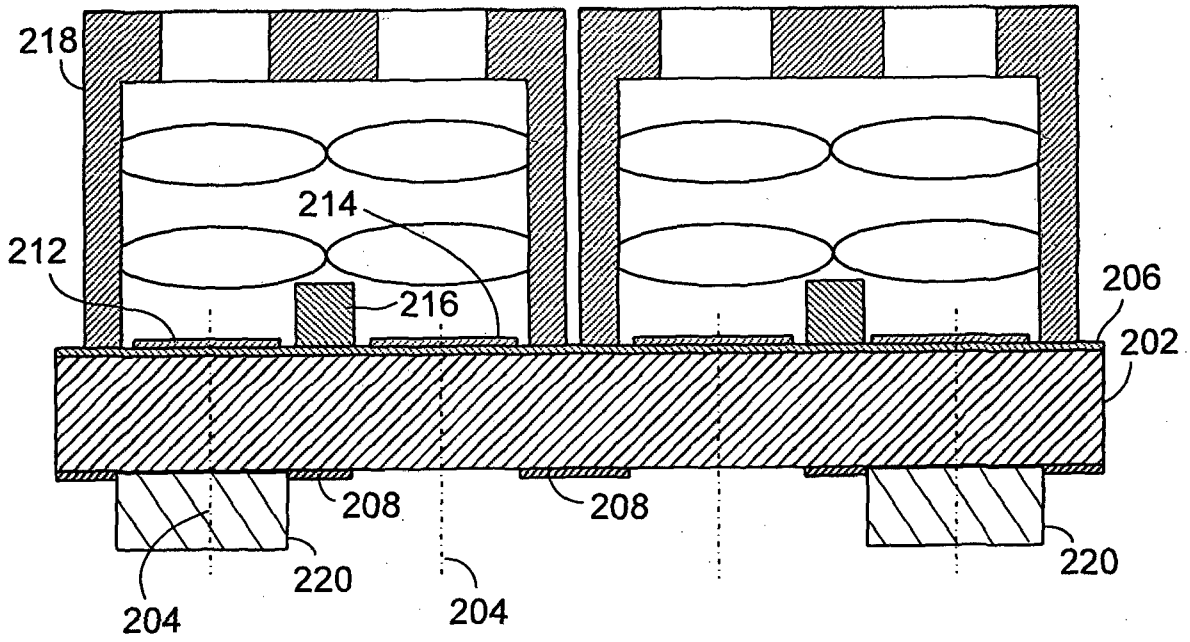


FIG. 27

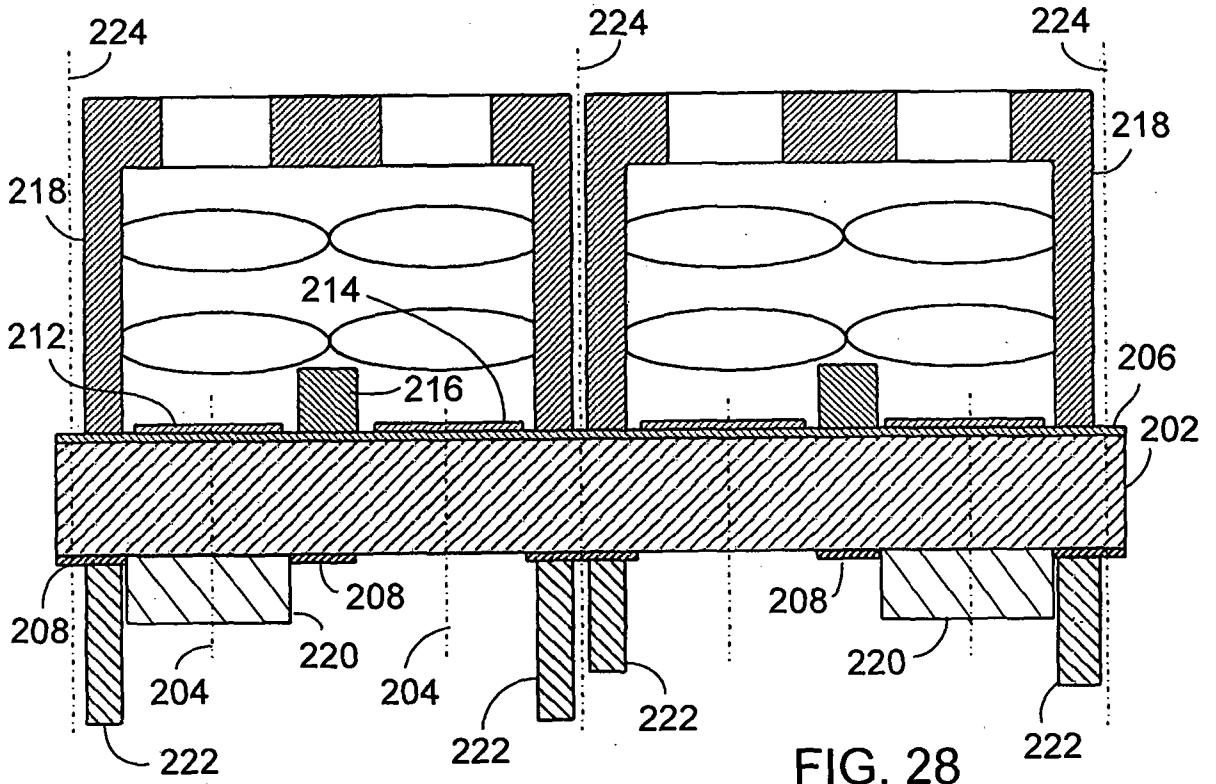


FIG. 28

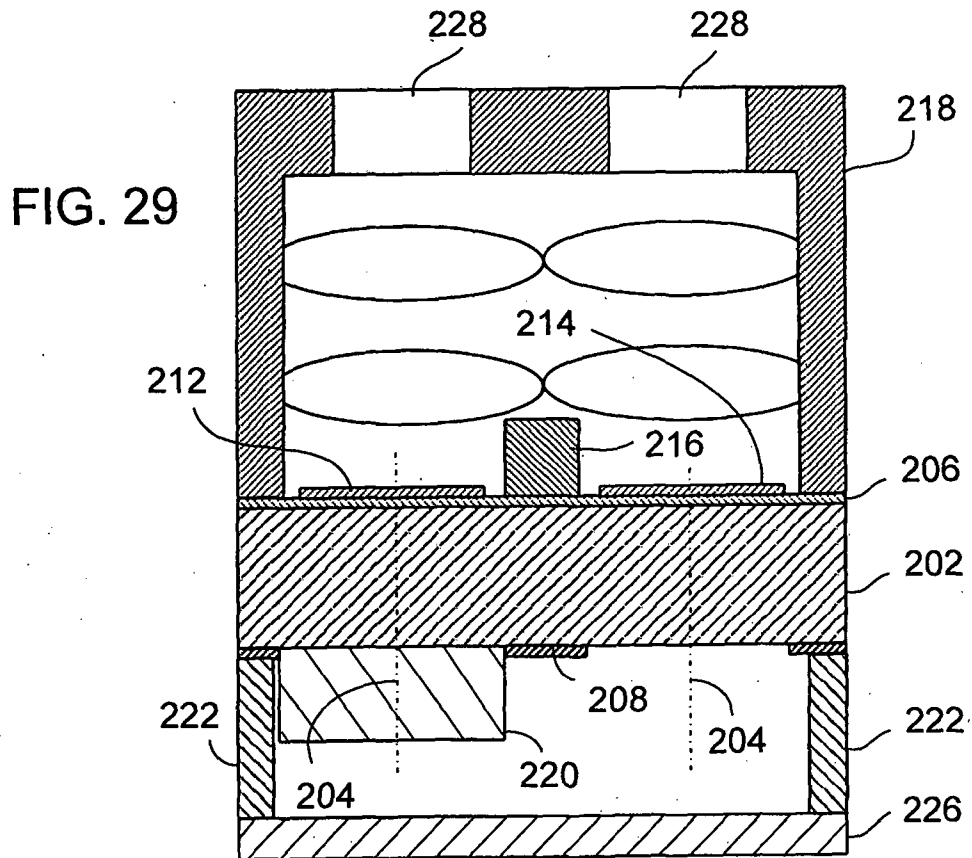


FIG. 29

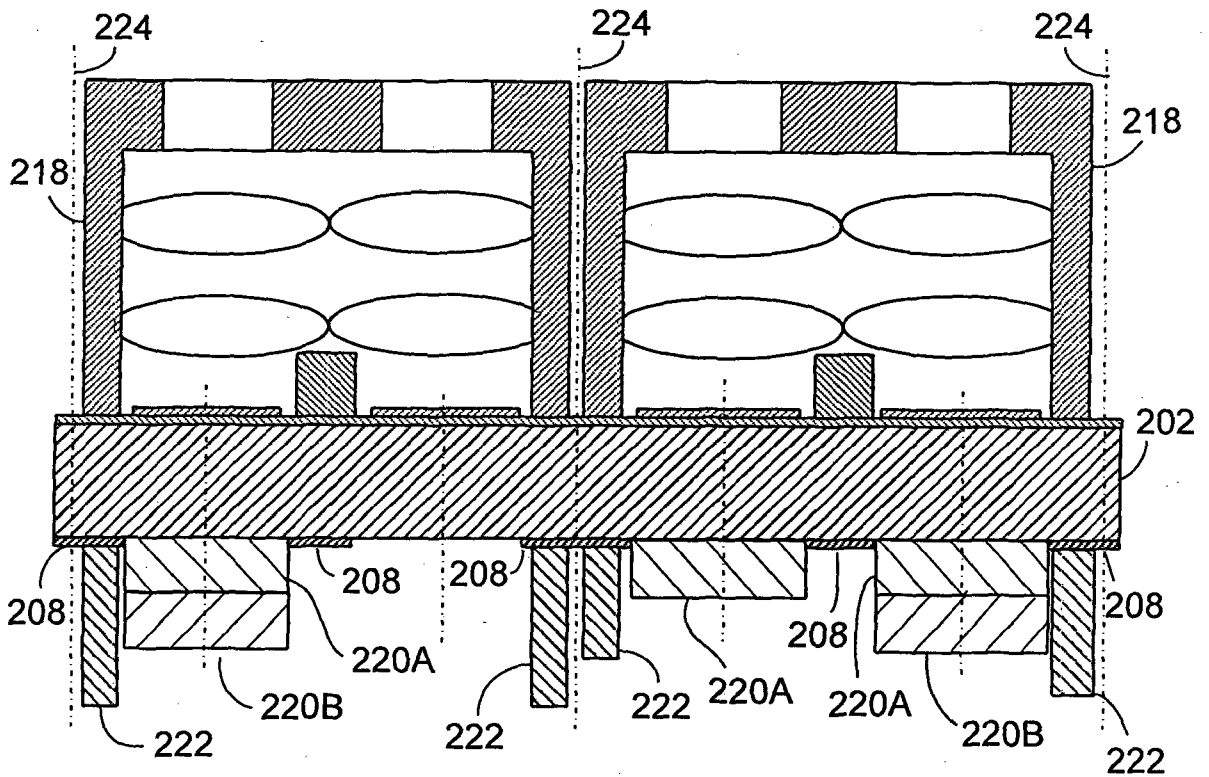


FIG. 30

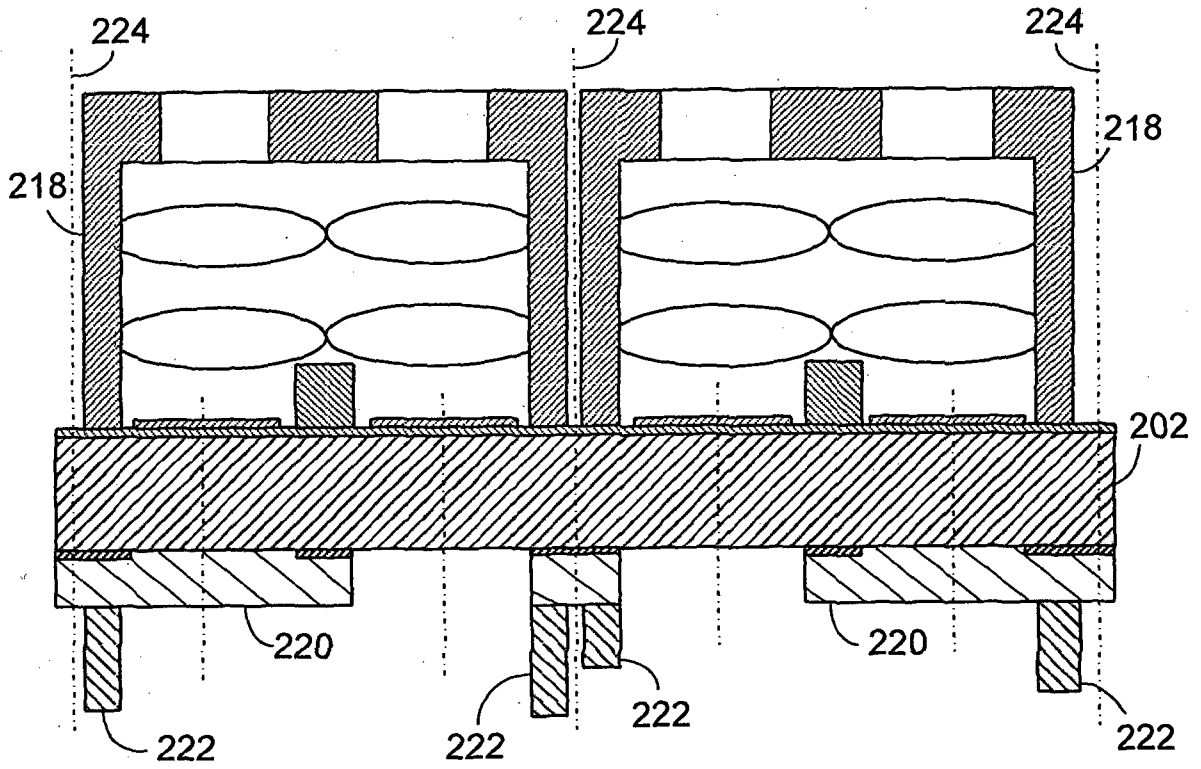


FIG. 31

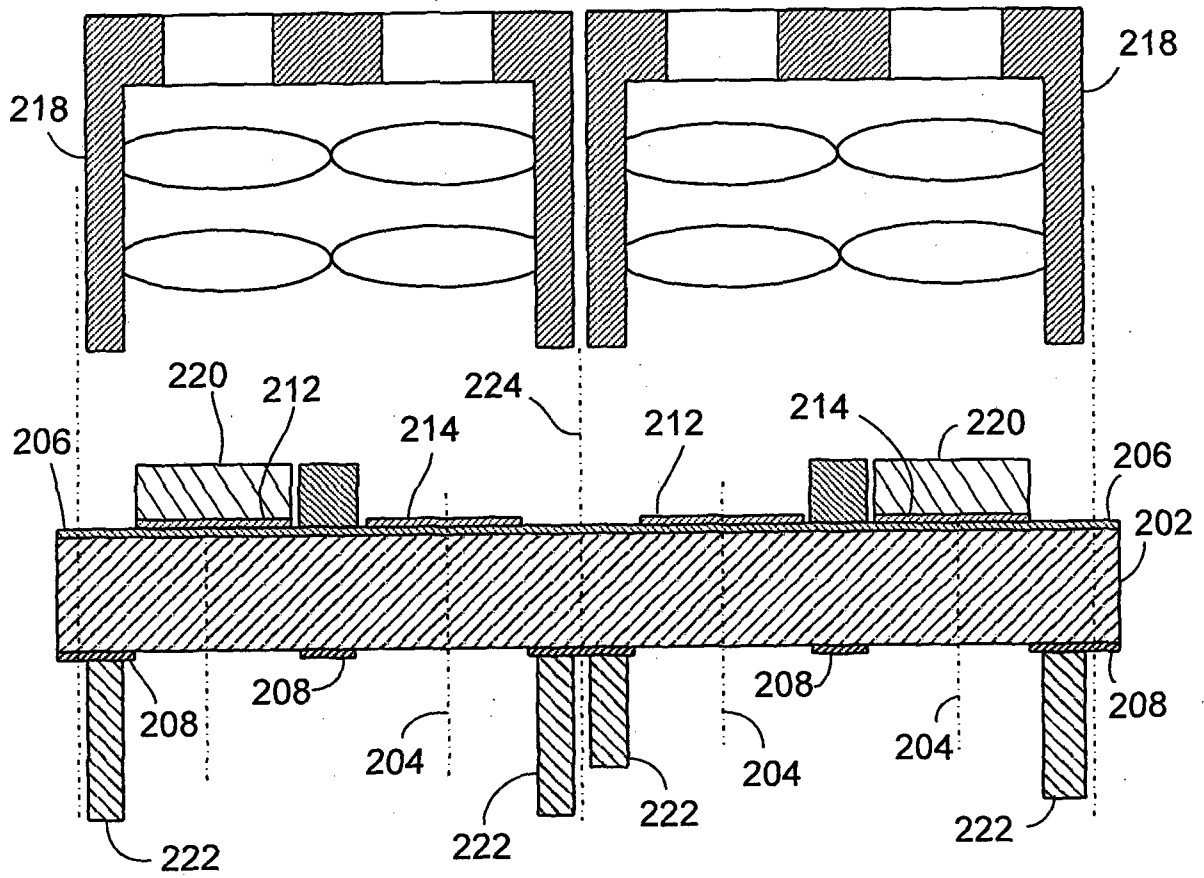


FIG. 32

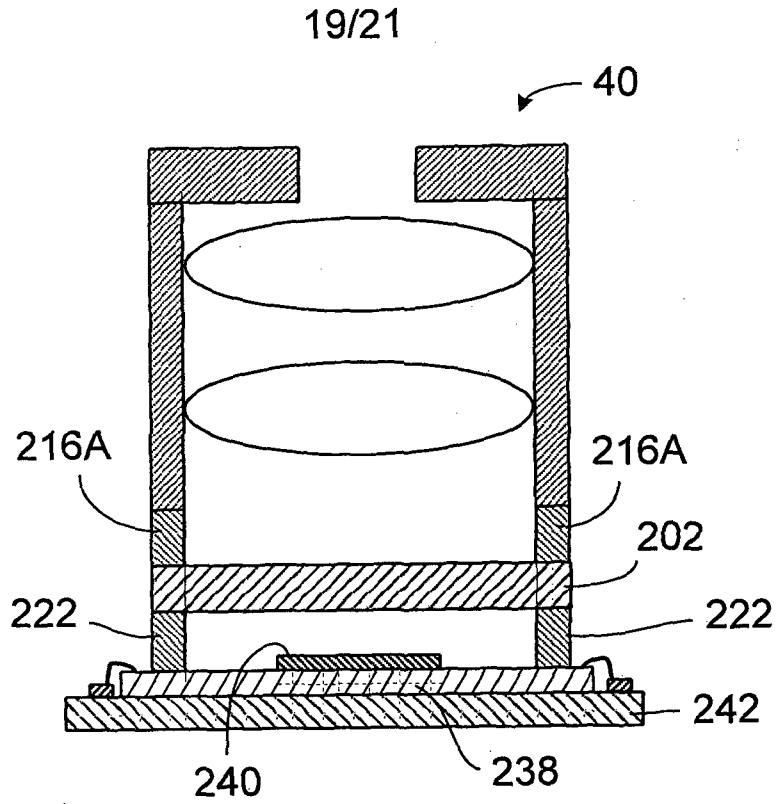


FIG. 33

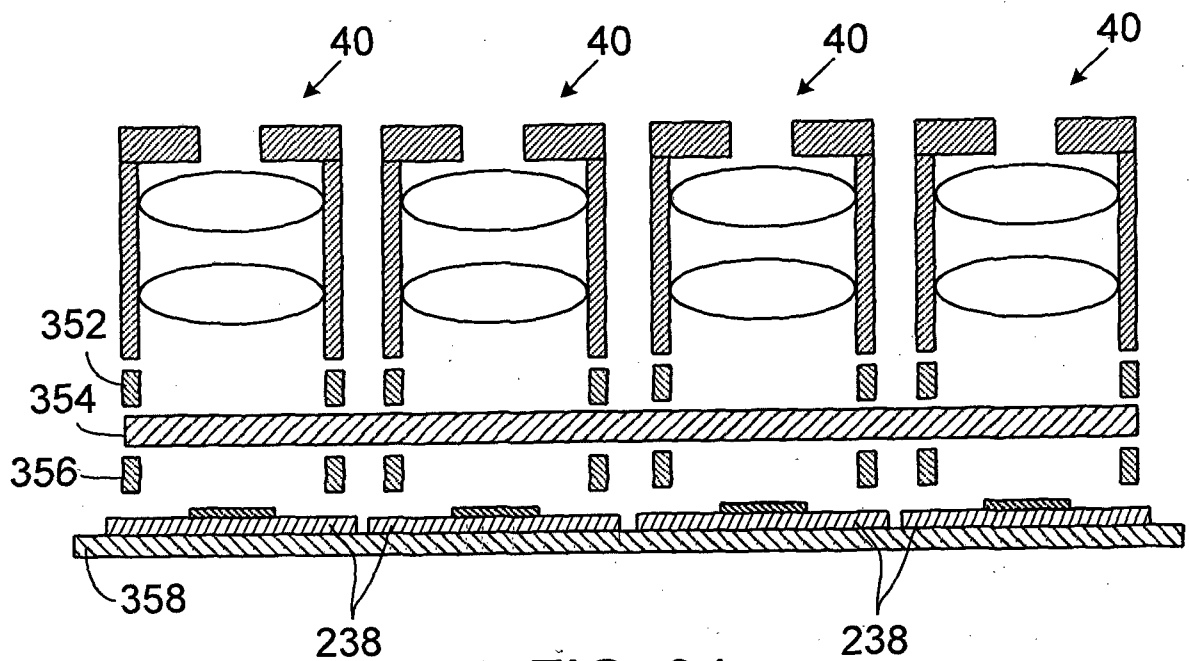


FIG. 34

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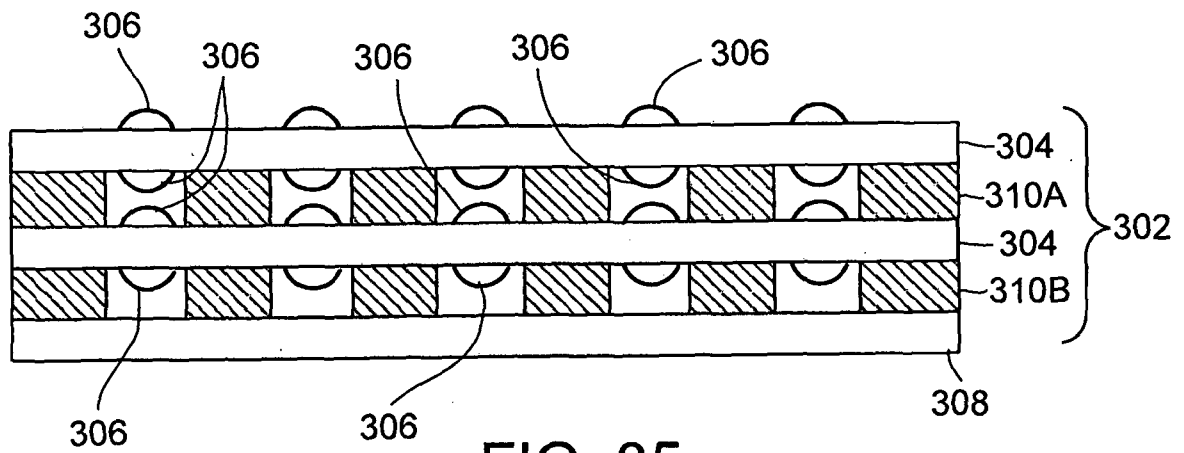


FIG. 35

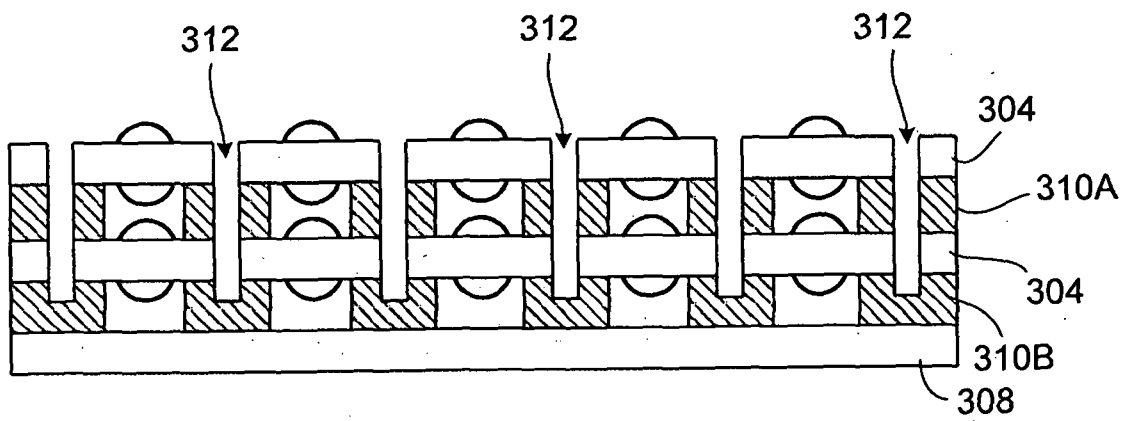


FIG. 36

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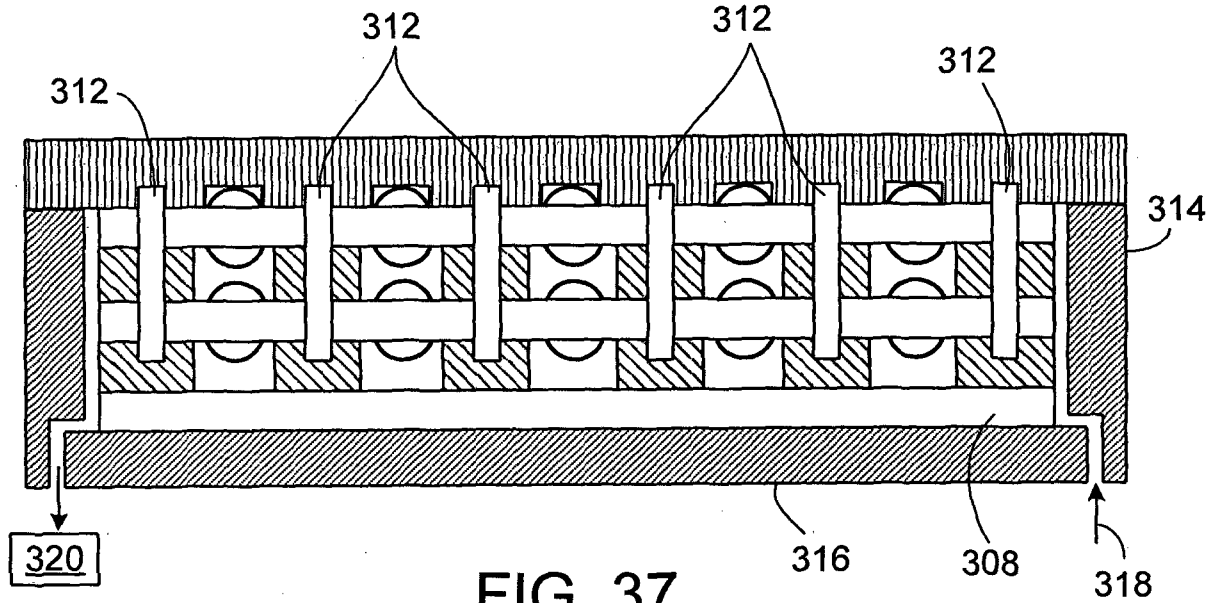


FIG. 37

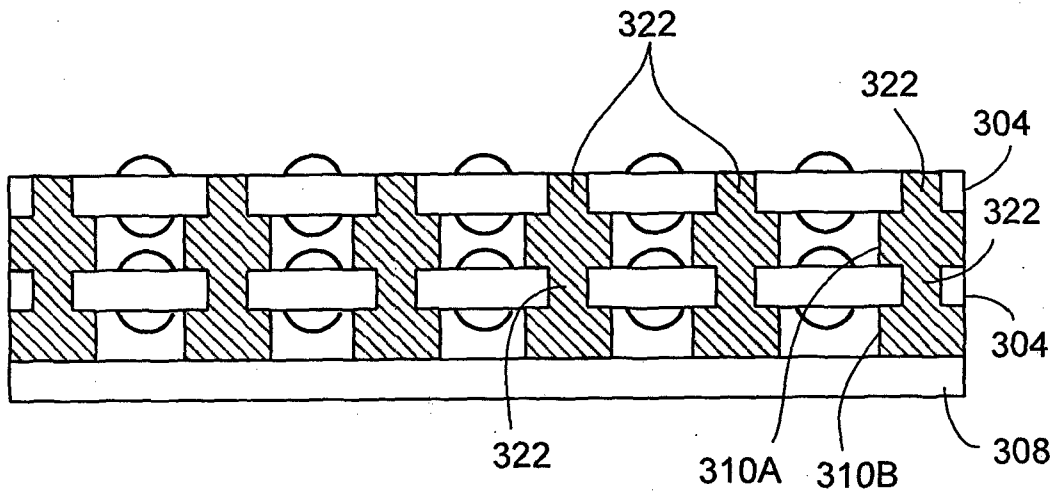


FIG. 38

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/SG2013/000470

## A. CLASSIFICATION OF SUBJECT MATTER

G02B 13/00 (2006.01) G02B 7/02 (2006.01) H01L 31/0232 (2014.01) H04N 5/225 (2006.01)

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

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**Databases:** GOOGLE PATENTS, GOOGLE SCHOLAR, ESPACENET, EPODOC, WPI**Keywords:** Lens Stack, Wafer Stack, Lens System, Substrate, transparent, wavelength, FFL, Focal Length, Adjust, Thickness, micro-machining, lithography, filter, spacer, optical power, focus and similar terms.

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	



Further documents are listed in the continuation of Box C



See patent family annex

* Special categories of cited documents:		
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art	
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family	
"P" document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search  
28 January 2014Date of mailing of the international search report  
28 January 2014

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AUSTRALIAN PATENT OFFICE  
(ISO 9001 Quality Certified Service)  
Telephone No. 0262832814

## INTERNATIONAL SEARCH REPORT

International application No.

C (Continuation).

DOCUMENTS CONSIDERED TO BE RELEVANT

**PCT/SG2013/000470**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	WO 2010/074743 A1 (TESSERA NORTH AMERICA, INC.) 01 July 2010 Abstract, Figure 13, [0008], [0015], [0043 - 0048], [0061 - 0063] Abstract, Figure 13, [0008], [0015], [0043 - 0048], [0061 - 0063]	1 - 10, 12 - 14, 19 - 28, 33 - 37, 39 11, 15 - 18, 29 - 32, 38
Y	WO 2011/156926 A1 (HEPTAGON OY) 22 December 2011 Pages 4, 8, 9	11, 15 - 18, 29 - 32, 38
A	EP 2341540 A2 (KINGPAK TECHNOLOGY INC.) 06 July 2011 [0022 - 0024]	8, 13 - 14, 21, 26 - 28
X A	WO 2007/030226 A2 (CYPRESS SEMICONDUCTOR CORPORATION) 15 March 2007 Figure 5, [0008], [0022 - 0025], [0033], [0038], [0040] Figure 5, [0008], [0022 - 0025], [0033], [0038], [0040]	51 - 52 40 - 50
A	WO 2008/044937 A1 (IGNIS DISPLAY AS) 17 April 2008 Whole Document	1 - 52
A	WO 2011/063347 A2 (PELICAN IMAGING CORPORATION) 26 May 2011 Whole Document	1 - 52

**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1.  Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:  
the subject matter listed in Rule 39 on which, under Article 17(2)(a)(i), an international search is not required to be carried out, including
2.  Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3.  Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

**Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

**See Supplemental Box for Details**

1.  As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2.  As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3.  As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4.  No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

**Remark on Protest**

- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.

**Supplemental Box****Continuation of: Box III**

This International Application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept.

This Authority has found that there are different inventions based on the following features that separate the claims into distinct groups:

- Claims 1 - 11, 12 - 21, 22 - 32, 33 - 39, 51, 52. The feature of removing selected portions of a substrate/FFL correction layer to provide focal length corrections for the lens system is specific to this group of claims.
- Claims 40 - 50. The feature of providing a plurality of colour filter layers disposed over different regions of the substrate, wherein the optical axis of each lens system intersects a respective one of the colour filter layers; a spacer disposed over the substrate between a respective pair of the colour filter layers, wherein the spacer is substantially non-transparent to light of the particular wavelength of range of wavelengths; an image sensor attached over a second side of the substrate is specific to this group of claims.

PCT Rule 13.2, first sentence, states that unity of invention is only fulfilled when there is a technical relationship among the claimed inventions involving one or more of the same or corresponding special technical features. PCT Rule 13.2, second sentence, defines a special technical feature as a feature which makes a contribution over the prior art.

When there is no special technical feature common to all the claimed inventions there is no unity of invention.

In the above groups of claims, the identified features may have the potential to make a contribution over the prior art but are not common to all the claimed inventions and therefore cannot provide the required technical relationship. The only feature common to all of the claimed inventions is to mount/attach a plurality of singulated lens systems over a substrate. However it is considered that this feature is generic in this particular art.

Therefore this common feature cannot be a special technical feature. Hence there is no special technical feature common to all the claimed inventions and the requirements for unity of invention are consequently not satisfied *a priori*.

It is considered that search and examination for the second invention will require more than negligible additional search and examination effort over that for the first invention, and therefore an additional search fee is warranted.

## INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/SG2013/000470

This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document/s Cited in Search Report		Patent Family Member/s	
Publication Number	Publication Date	Publication Number	Publication Date
WO 2010/074743 A1	01 Jul 2010	None	
WO 2011/156926 A1	22 Dec 2011	EP 2580781 A1	17 Apr 2013
		JP 2013531812 A	08 Aug 2013
		KR 20130093072 A	21 Aug 2013
		SG 186214 A1	30 Jan 2013
		TW 201222795 A	01 Jun 2012
		US 2013162882 A1	27 Jun 2013
		WO 2011156926 A1	22 Dec 2011
EP 2341540 A2	06 Jul 2011	TW 201123368 A	01 Jul 2011
		US 2011156188 A1	30 Jun 2011
WO 2007/030226 A2	15 Mar 2007	JP 2009507392 A	19 Feb 2009
		US 2007052050 A1	08 Mar 2007
		WO 2007030226 A2	15 Mar 2007
WO 2008/044937 A1	17 Apr 2008	CN 101600976 B	09 Nov 2011
		EP 2074444 A1	01 Jul 2009
		JP 2010506233 A	25 Feb 2010
		JP 5244806 B2	24 Jul 2013
		KR 20090107484 A	13 Oct 2009
		US 2010091389 A1	15 Apr 2010
		US 8045280 B2	25 Oct 2011
		WO 2008044937 A1	17 Apr 2008
WO 2011/063347 A2	26 May 2011	CN 102037717 B	06 Nov 2013
		CN 103501416 A	08 Jan 2014
		EP 2289235 A2	02 Mar 2011
		EP 2502115 A2	26 Sep 2012
		JP 2011523538 A	11 Aug 2011
		KR 20110010784 A	07 Feb 2011
		US 2011122308 A1	26 May 2011
		US 8514491 B2	20 Aug 2013
		US 2011069189 A1	24 Mar 2011
		US 2011080487 A1	07 Apr 2011
		US 2013308197 A1	21 Nov 2013
		WO 2009151903 A2	17 Dec 2009
		WO 2011063347 A2	26 May 2011

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/SG2013/000470**

This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

**Patent Document/s Cited in Search Report****Patent Family Member/s****Publication Number****Publication Date****Publication Number****Publication Date****End of Annex**

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

Form PCT/ISA/210 (Family Annex)(July 2009)