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(54) **Title**: WAFER LEVEL CAMERA MODULE WITH ACTIVE OPTICAL ELEMENT

(57) **Abstract**: A wafer level camera module may be easily connected to a host device via mounting surface contacts. The module includes an electrically controllable active optical element and a flexible printed circuit that provides electrical connection between the optical element and surface conductors on a mounting surface of the module. The surface conductors may be a group of solder balls, and the module may have another group of solder balls that make connection to another electrical component of the module, such as an image sensor. All of the solder balls may be coplanar in a predetermined grid pattern, and all of the components of the device may be surrounded by a housing such that the camera module is an easily mounted ball grid array type package.

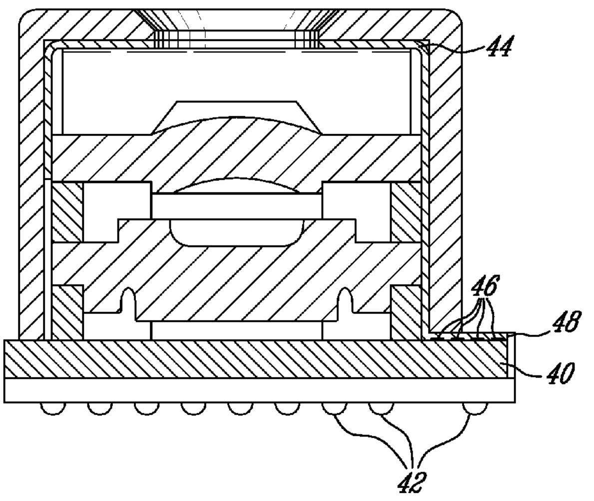

FIG_7

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WAFER LEVEL CAMERA MODULE WITH ACTIVE OPTICAL ELEMENT

Technical Field

[001] The present invention relates generally to the field of optical devices and, more specifically, to a wafer level camera module with an active optical element and the packaging thereof.

Background

[002] Lens structures for optical devices, such as cameras, consist of multiple lens elements assembled in a single barrel or stacked in a wafer form, utilizing spacers, to create fixed focus lens assemblies. These lens structures have a fixed focal plane and are mechanically moved to focus on objects that are located at varying distances from the camera system.

[003] A wafer level camera module consists of a CMOS sensor, normally packaged in a Chip Scale Package, and a wafer level lens structure, consisting of multiple replicated lenses on glass substrates. In such a configuration, no electrical connection is required between these parts.

[004] Tunable liquid crystal lenses (TLCL) having a flat layer construction are known in the art, as described in PCT International Patent Application Publications no. WO *2007/098602,* published on September 7, 2007, WO/2009/146529 and WO/2009/146530, published on 10 December 2009, and WO/2010/022503, published on 4 March 2010, the specifications of which are hereby incorporated by reference as if fully set forth herein.

[005] In U.S. Provisional Patent Application Serial No. *61/175,025*, which was filed May 3, 2009 and the substance of which is incorporated herein by reference, there is disclosed a wafer level camera with an active optical element positioned within a lens stack of the lens assembly. By applying a

required electrical signal to the active element, it is possible to modify an optical property of the lens assembly without any mechanical movement. In the case of a TLCL as the active optical element, the focal plane of the lens structure can be moved, thus creating a variable focus (e.g. auto focus) device.

[006] When a wafer level camera includes an active optics element, such as a TLCL, one or more electrical connections are required to contact the active optics element to the camera substrate, most likely a Chip Scale Package or a sensor on a printed circuit board (PCB). In U.S. Provisional Patent Application Serial No. *61/175,025*, this requirement is met by an integrated electrical connection structure that is provided to enable electrical contacts as part of the lens barrel assembly. At least one electrical contact provides an electrically conductive path between an outer surface of the lens mounting structure and the active optical element. The contact may be a stamped metallic piece (lead) with an incorporated spring element to ensure reliable electrical connection to a contact on a receiving device to which the lens apparatus is mounted. Alternatively, a molded interconnect device (MID), used in place of lead frames in the device, may be used to create a connection between the active optical element and the camera housing or surrounding devices, in which case connection to the embedded active optical element may be achieved by means of conductive adhesives.

Summary

[007] In accordance with the present invention, a wafer level camera module is provided that includes an electrically controllable active optical element, such as a tunable liquid crystal lens. The module has an electrical conduction path from the active optical element to a mounting surface of the

camera module, where a surface conductor is located. The surface conductor is in electrical contact with the electrical conduction path and is configured to make electrical contact with a conductor on a host substrate to which the camera module is mounted.

[008] In an exemplary embodiment, the surface conductor includes at least one solder ball that is part of a ball grid array-like package when the camera module is fully assembled. The camera module may also be compatible with an automatic pick-and-place process for mounting the camera module to the host substrate. The surface conductor may also be part of a first group of surface conductors for the active optical element. The module may also include a second group of surface conductors that are arranged to be co-planar with the first group, and the first group and second group of surface conductors may be arranged in a predetermined pattern on the mounting surface of the module. The second group of conductors may, for example, provide electrical connection to an imaging device of the camera module, such as a CMOS sensor pre-assembled in a ball grid array package suitable for wafer level assembly.

[009] In an exemplary embodiment of the invention, the electrical conduction path from the active optical element to the mounting surface may make use of a flexible circuit board that has a stiffener, on the bottom surface of which is located the first group of surface conductors. Upon assembly of the camera module, the flexible circuit board may at least partially surround the active optical element while providing electrical contact between it and the first group of surface conductors on the stiffener. The electrical connection between the flexible printed circuit and the active optical element may include conductive film bonding, such as an anisotropic conductive film bonding process, or a conductive adhesive. The flexible printed circuit may be

mounted in such a way as to ensure that, once assembled, the flexible printed circuit is able to compress or bend to accommodate variations in lens height tolerance.

[0010] The stiffener of the flexible printed circuit may have alignment holes to ensure proper alignment between the first group of surface conductors and the second group. In addition, the camera module may also include a housing that receives and contains all of the elements of the camera module upon its assembly, and that housing may support and position the stiffener in order to ensure proper relative positioning between the first group and the second group of surface conductors. In particular, the housing may include a flange for receiving the stiffener, where the flange includes at least one alignment hole arranged to align with at least one alignment hole of the stiffener upon camera module assembly. The housing may, for example, be a polymer or plastic material.

Brief Description of the Drawings

[0011] The invention will be better understood by way of the following detailed description of embodiments of the invention with reference to the appended drawings, in which:

[0012] Figure 1 is a top perspective view of a wafer level camera module according to the present invention;

[0013] Figure 2 is a bottom perspective view of the camera module of Figure 1.

[0014] Figure 3 is an exploded view of the wafer level camera module of Figure 1, showing the various components of the camera module as assembled

[0015] Figure 4 is a perspective view of the camera module of Figure 1, partially disassembled to reveal a flexible contact structure provided within the stack of elements;

[0016] Figure 5A is a side view of the wafer level camera module of Figure 1;

[0017] Figure 5B is a bottom view of the wafer level camera module of Figure 1;

[0018] Figure 6 is a cross-sectional side view of the wafer level camera module of Figure 1.

[0019] Figure 7 is a cross-sectional side view of the wafer level camera module of an alternative embodiment similar to Figure 1 in which the active element contact connect with the top surface of the image sensor.

Detailed Description

[0020] Shown in Figure 1 is a fully assembled wafer level camera (WLC) module including an active optical element, according to a non-limiting embodiment of the present invention. Such a camera module may be intended for integration into a portable telephone, for example, or more specifically for mounting on the main printed circuit board (PCB) of a cellular telephone. The camera housing 10 in this embodiment is roughly cubical, although it may take a number of different forms as well. The camera housing (or “cover”) 10 is a molded component that prevents light leakage to the camera and protects the camera module. The camera cover is designed and molded in such a way that it is able to receive and contain all of the various elements of the camera module. In one implementation, the camera housing is made of a polymer material, such as a plastic. The housing 10 also includes a flange 12 that, as discussed in more detail below, is used to cover a portion of an internal flexible circuit board, and includes alignment holes 14 via which the internal components of the camera may be mutually aligned. The cover 12 sits on a base substrate 16, which may be an optical detector package that includes a CMOS image sensor in a ball grid array (BGA) chip-scale package (CSP) suitable for wafer level assembly. As assembled, the WLC module of Figure 1 is ready for direct reflow mounting to a PCB, for example by an automatic pick-and-place process.

[0021] As shown in Figure 2, which is a perspective view of the underside of the assembly shown in Figure 1, the bottom surface of the base substrate 16 has a plurality of solder balls 18 via which electrical contact may be made with device components, such as an image sensor. Solder balls 20 are also located on the underside of a stiffener portion 22 of a flexible circuit board, which is discussed in more detail below. Thus, the assembly process itself provides for all of the necessary electrical connections to the active optical element of the camera, such as a tunable liquid crystal lens (TLCL), without requiring any additional steps to make the necessary electrical contact.

[0022] The active optical element can comprise a tunable lens, shutter, beam steering device, diaphragm, variable filter, etc. as will be apparent to a person skilled in the art.

[0023] As seen in the exploded view of Figure 3, the wafer camera module is formed of various separate elements, which are assembled together within the molded camera cover. In a specific, non-limiting example of implementation of the present invention, these elements include an image CMOS sensor 23, a wafer level fixed lens structure 24, an active optical element such as TLCL 26 and a flexible printed circuit 28.

[0024] The image CMOS sensor is pre-packaged in ball grid array (BGA) chip-scale package (CSP) 16 suitable for wafer level assembly. As shown in

Figure 2, the CMOS sensor BGA-CSP is characterized by a plurality of solder balls provided on its bottom surface. These solder balls are intended for reflow soldering to a PCB upon mounting of the fully assembled camera module to a device, such as the PCB of a cellular phone, thus making electrical connections between the image sensor and the device substrate.

[0025] The wafer level fixed lens structure 24 includes multiple lens elements suitable for focusing onto the image CMOS sensor. This fixed lens structure, which may be mounted on a glass substrate and may be characterized by various shapes, sizes and thicknesses, acts to focus light from a subject that is collected via the aperture of the camera. In one embodiment, the wafer level fixed lens structure is characterized by multiple glass layers with replicated surfaces, forming an optical structure similar to conventional lens elements in a camera. Light from a subject in front of the fixed lens structure is collected via entrance aperture 30 and is focused by the lens structure to form an image on a desired imaging device, in this case the CMOS sensor 23 of the WLC. The TLCL can be located at any desired position within the stack of lenses. The aperture of the TLCL can be made smaller when the TLCL is located within the stack at a position where the lens aperture is smaller.

[0026] The active optical element of the module shown in Figure 3 is a tunable lens, providing an auto focus function for the wafer level camera. In the present embodiment, the tunable lens is a tunable liquid crystal lens (TLCL), such as that discussed in U.S. Provisional Patent Application Serial No. 61/059,274, filed June 6, 2008, the substance of which is incorporated herein by reference. As is discussed in this and other disclosures, a TLCL is a liquid crystal based lens structure for which the focusing power changes with changes to an applied electric field. As the electric field is typically

[0027] In the example illustrated in Figure 3, the TLCL 26 is separate from the wafer level fixed lens structure 24, positioned adjacent the fixed lens structure within the assembled camera module. However, the TLCL 26 may also be located at different positions within the assembled camera module, without departing from the scope of the present invention. For example, the TLCL 26 may be integrated within the fixed lens structure, sandwiched between two of the layers, thus forming a variable focus lens structure. Advantageously, when a TLCL is included in the lens stack of the fixed lens structure, the focus plane of the fixed lens structure can be actively adjusted to compensate for improper distance of the lens stack from the CMOS sensor. It may also be advantageous to locate the TLCL at a position in the lens camera module where the light passing through it will be at a relatively narrow focus, that is, where a cross sectional area of the light passing through the TLCL is minimum. In this way, the size of the TLCL and the actively controlled area of the lens may be minimized. In another variation of the invention, the TLCL may be part of a structure that has a TLCL located in a substrate to which is attached one or more fixed lenses. A lens structure such as this is disclosed in International Patent Application PCT/CA2009/001181, the substance of which is incorporated herein by reference.

[0028] Specific to the present invention, flexible printed circuit (FPC) 28 is provided within the camera module to create electrical connections from the active optical element (i.e., the TLCL 26) to the substrate on which is mounted the camera module (e.g., the PCB of a cellular phone). As shown in the example of Figure 3, the FPC 28 is shaped to receive and contain the TLCL 26 of the camera module, as well as at least a portion of the fixed lens structure 24. More specifically, the FPC 28 has a substantially flat upper surface, bearing an aperture matching the camera aperture 30, with four walls 32 extending downwardly therefrom. A particular one of these walls has a portion 34 that extends to stiffener 22 of the FPC, the height of this particular wall being such that, upon assembly of the WLC module, the stiffener 22 of the FPC is co-planar with the CSP-BGA sensor package 16. The perspective view of Figure 4, which depicts the assembled camera module without cover 10, shows how the FPC 28 fits over the TLCL 26 and fixed lens structure 24, such that the bottom of stiffener 22 is aligned with the bottom of base substrate 16.

[0029] As shown in Figure 2, the stiffener 22 of the FPC 28 includes multiple solder balls 20 provided on the bottom thereof, for reflow soldering of the PCB to a host circuit board upon mounting of the camera module thereto. The solder balls 20 on the stiffener 22 are characterized by a specific spacing, size and shape in order to match that of the solder balls 18 of the sensor BGA. This similarity among all of the solder balls and their spacing is important to ensure that the fully assembled WLC, including the TLCL, is a BGA-like package. In addition to being shown in Figure 2, the spacing and positioning of the solder balls 18 and 20 in the present embodiment are shown in Figures 5A and 5B which represent, respectively, a side view and a bottom view of the assembled camera module.

[0030] As is well known in the art, a FPC bears conductive pathways or traces that serve to make electrical connections. In the case of the WLC module of the present invention, the conductive pathways of the FPC 28 allow convenient electrical signal routing between the TLCL 26 and the PCB of a cellular phone. More specifically, the FPC is designed such that its conductive pathways or traces are provided thereon according to a layout that ensures electrical connection can be made to one or more contact points of the TLCL, when this TLCL 26 is received within the FPC 28. These conductive pathways or traces run down the particular wall of the FPC that ends in the stiffener 22, thus conducting signals from the active optical element down to the conductors (i.e., solder balls 20) of the stiffener 22.

[0031] The FPC may be mounted and electrically connected to the TLCL 26 by way of conductive film bonding, such as an anisotropic conductive film (ACF) bonding process, or using conductive adhesive (e.g., conductive sheet adhesives), among many other possibilities. Advantageously, the use of conductive sheet adhesives to mount the FPC to the TLCL allows for the FPC to strain-relieve itself as it conforms to the lens stack of the camera module. Alternatively, at least one side of the FPC 28 may be given clearance space and left without bonding to the TLCL, thus allowing the FPC to compress or otherwise bend to accommodate variations in lens height tolerance.

[0032] In the context of a fully assembled WLC, the stiffener 22 of the FPC may be reflow soldered to a substrate of the WLC module, for example a cell phone PCB. Accordingly, the FPC 28 is operative to conduct electrical signals between the variable focus lens structure (i.e., TLCL 26) of the WLC module and the PCB, along the vertical wall of the camera module and via the electrical contact points made between the stiffener 22 and the PCB. As shown in Figure 2, the stiffener 22 of the FPC 28 is characterized by a pair of alignment holes 36 used to align the FPC to the camera cover 10, as will be discussed in further detail below. This stiffener 22 is also used to create proper structure for attachment of the camera module to the PCB.

[0033] Upon assembly, the cover 10 is aligned with and attached to both the sensor BGA 16 and the FPC 28, in order to maintain these two elements in proper aligned position within the cover 10. As discussed above, the camera cover (or housing) 10 includes a flange 12 at its bottom end, which has alignment holes 14 for providing proper alignment of the elements of the camera module. More specifically, upon assembly of the WLC module, the stiffener 22 of the FPC 28 is received within the flange 12 of the camera cover 10, and the alignment holes 36 of the stiffener 22 are aligned with the alignment holes 14 of the camera cover flange 12, thus ensuring proper alignment of the solder balls 20 on the FPC with the solder balls 18 of the CMOS sensor BGA 16. More specifically, the solder balls 20 of the FPC stiffener 22 are positioned to be physically parallel with the solder balls 18 of the sensor BGA 16 when the camera is fully assembled.

[0034] The WLC module may be constructed following different assembly sequences, depending on test and yield requirements of different elements of the camera. In a specific, non-limiting example, the elements of the WLC module are assembled in the following sequence:

1. Attach the TLCL to the wafer level fixed lens structure in wafer form.
2. Assemble this variable focus lens structure to a CSP packaged wafer of CMOS sensors.
3. Dice and separate the modules to form individual wafer level camera modules.

4. Attach the FPC to a WLC module using an anisotropic conductive film (ACF) bonding process or a conductive adhesive.
5. Attach the camera cover to the CSP package and FPC, using the alignment holes to create proper alignment of solder balls on the FPC to the camera cover and in turn to the solder balls on the BGA-CSP.

[0035] The fully assembled wafer level camera module is shown in the external perspective view of Figure 1, and is also shown in partial cross-section in Figure 6 (in this view, the TLCL is obscured by a vertical portion of the FPC 28, which is shown to indicate its position relative to the module components). The module is an efficiently structured BGA-like package that includes an active optical element, notably the auto-focus TLCL along with a fixed lens structure 24 and FPC 28. Advantageously, this packaging of the WLC with active optical element allows for the active optical element to be assembled to the PCB of a cellular phone like any other BGA, without the need for additional or special assembly steps to make the necessary electrical connections to the active optical element. The packaged WLC module, in its final assembled form, is a fully testable component that may be mounted to a PCB using an automatic pick-and-place process and reflow soldering.

[0036] The control of the focus can be implemented using control circuitry (not shown) connected to the TLCL. For a description of an autofocus circuit for a TLCL, reference is made to PCT publication WO/2010/022080 published on 25 February 2010.

[0037] An alternative embodiment of the invention is shown in Figure 7. In this embodiment, the base substrate 40 extends further than the base substrate 16 of Figures 1-6 and has solder balls 42 that provide connection points both for the image sensor and the for the active optical element. Electrical contact to the active optical element is made via flexible printed circuit 44, which makes contact with conductive pads 46 on the top of the substrate 40 that are, in turn, connected to respective solder balls 42 on the bottom surface of the substrate. The flexible printed circuit 44 is similar to flexible printed 28 of the foregoing embodiments, but does not include stiffener 22. Rather, the contact portion 48 has electrical contacts that make a connection with the conductive pads 46 of the substrate. Thus, in this embodiment, there is only one continuous contact surface on the base of the device, and there is no need to align two portions at the mounting surface of the camera module.

[0038] It is important to note that the above-described embodiments and examples of implementation of the present invention have been presented for illustration purposes but that additional variants and modification are possible and should not be excluded from the scope of the present invention. For example, the wafer level camera module may include additional elements, with varying functionality, without departing from the scope of the present invention.

What is claimed is:

CLAIMS

1. A wafer level camera module comprising:

an electrically controllable active optical element;

an electrical conduction path from the active optical element to a mounting surface of the camera module; and

a surface conductor located on a mounting surface of the camera module, the surface conductor being in electrical contact with said electrical conduction path and being configured to make electrical contact with a conductive path on a host substrate to which the camera module is mounted.

2. A wafer level camera module as defined in claim 1, wherein said the surface conductor comprises at least one solder ball that is part of a ball grid array-like package when said camera module is fully assembled.

3. A wafer level camera module as defined in claim 1 or 2, wherein said camera module is compatible with an automatic pick-and-place process for mounting said camera module to the host substrate.

4. A wafer level camera module as defined in claim 3, wherein the surface conductor is part of a first group of surface conductors for the active optical element, and wherein the camera module further comprises a second group of surface conductors that are arranged to be co-planar with the first group.

5. A wafer level camera module as defined in claim 4, wherein the first group of surface conductors and said second group of surface conductors are arranged in a predetermined pattern on said mounting surface.

6. A wafer level camera module as defined in claim 5, wherein said second group of surface conductors provide electrical connection to an imaging device of said camera module.

7. A wafer level camera module as defined in claim 6, wherein said imaging device is an image CMOS sensor pre-assembled in a ball grid array package suitable for wafer level assembly.

8. A wafer level camera module as defined in claim 5, wherein said electrical conduction path is part of a flexible printed circuit bearing said first group of surface conductors for said active optical element.

9. A wafer level camera module as defined in claim 8, wherein said flexible printed circuit includes a stiffener on a bottom surface of which is located the first group of surface conductors.

10. A wafer level camera module as defined in claim 9, wherein said flexible printed circuit at least partially surrounds said active optical element upon assembly of said camera module, said flexible printed circuit providing electrical contact between said active optical element and said first group of surface conductors on said stiffener.

11. A wafer level camera module as defined in claim 10, wherein said flexible printed circuit is electrically connected to said active optical element using either one of conductive film bonding or conductive adhesive.

12. A wafer level camera module as defined in claim 11, wherein said conductive film bonding is an anisotropic conductive film bonding process.

13. A wafer level camera module as defined in claim 10, wherein said flexible printed circuit is mounted and electrically connected to said active optical element in such a way as to ensure that, once assembled, said flexible printed circuit is able to compress or bend to accommodate variations in lens height tolerance.

14. A wafer level camera module as defined in claim 10, wherein said stiffener includes at least one alignment hole for ensuring proper alignment between the first group of surface conductors and the second group of surface conductors.

15. A wafer level camera module as defined in claim 14, wherein said camera module includes a housing for receiving and containing all elements of said camera module upon assembly thereof, said housing being operative to support and position said stiffener of said flexible printed circuit in order to ensure proper relative positioning between said the first group of surface conductors and the second group of surface conductors.

16. A wafer level camera module as defined in claim 15, wherein said housing includes a flange for receiving said stiffener of said flexible printed circuit, said flange including at least one alignment hole arranged to align with said at least one alignment hole of said stiffener upon assembly of said camera module.

17. A wafer level camera module as defined in claim 16, wherein said housing is made of polymer material.

18. A wafer level camera module as defined in claim 17, wherein said polymer material is a plastic material.

19. A wafer level camera module as defined in any one of claims 1 to 18, wherein said active optical element is a tunable lens.

20. A wafer level camera module as defined in claim 19, wherein said active optical element is a tunable liquid crystal lens.

21. A method for manufacturing a wafer level camera module having an active optical element, said method comprising:

arranging a stack of wafers of lenses including at least one wafer of active optical elements;

singulating the stack of wafers to obtain camera lens assemblies; and mounting the camera lens assemblies to image sensors with an electrical connection between contacts of said active optical elements and one of:

contacts provided on a top, image sensor side of said image sensors;

contacts provided at a bottom contact plane of said image sensors; and

contacts provided at a bottom contact plane of a package supporting said image sensors.

22. A method as defined in claim 21, wherein said mounting comprises:

providing a flexible printed circuit bearing surface conductors for said active optical element.

23. A method as defined in claim 22, wherein said flexible printed circuit is arranged within said camera module during assembly of said camera module such that said surface conductors for said active optical element are aligned co-planar with other solder connections of said camera module when said camera module is fully assembled.

24. A method as defined in claim 22, wherein said flexible printed circuit is arranged within said camera module includes arranging said solder connections for said active optical element and said other solder connections of said camera module to form a ball grid array-like package when said camera module is fully assembled.

25. A method as defined in any one of claims 21 to 24, wherein said active element has an edge connect structure.

26. A method as defined in any one of claims 21 to 25, wherein said active element is a tunable lens.

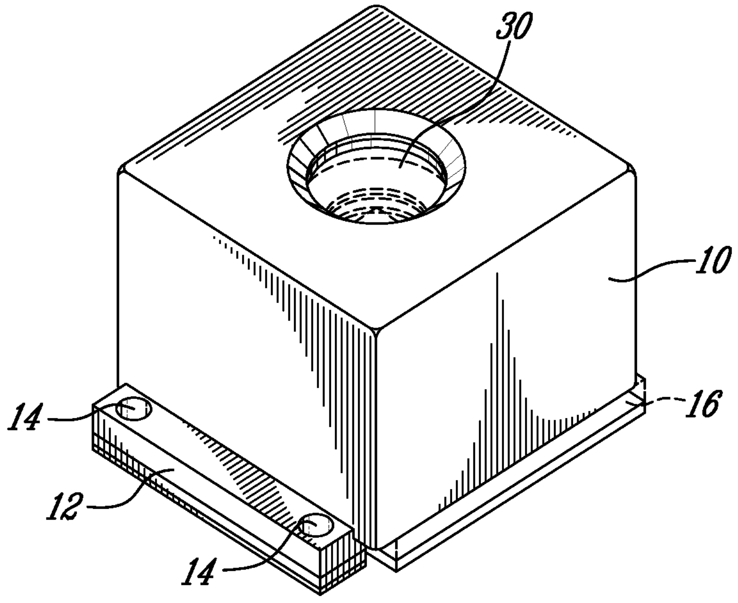

FIG. 1

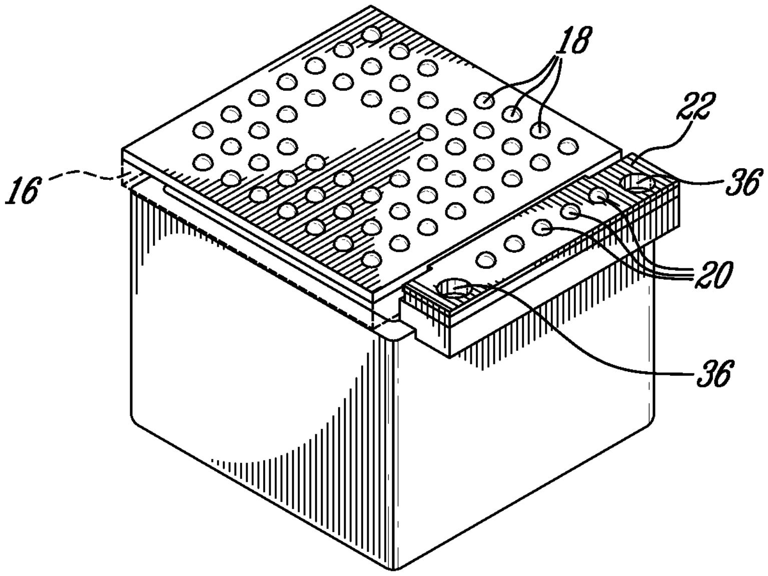

FIG. 2

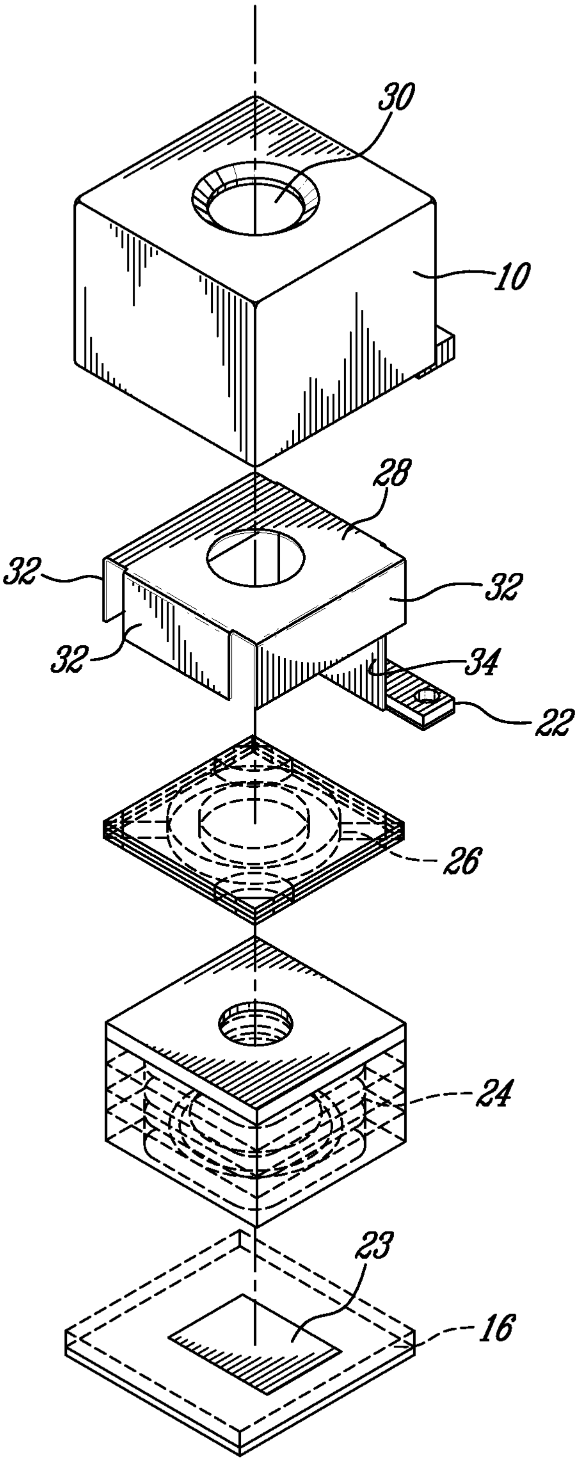

FIG. 3

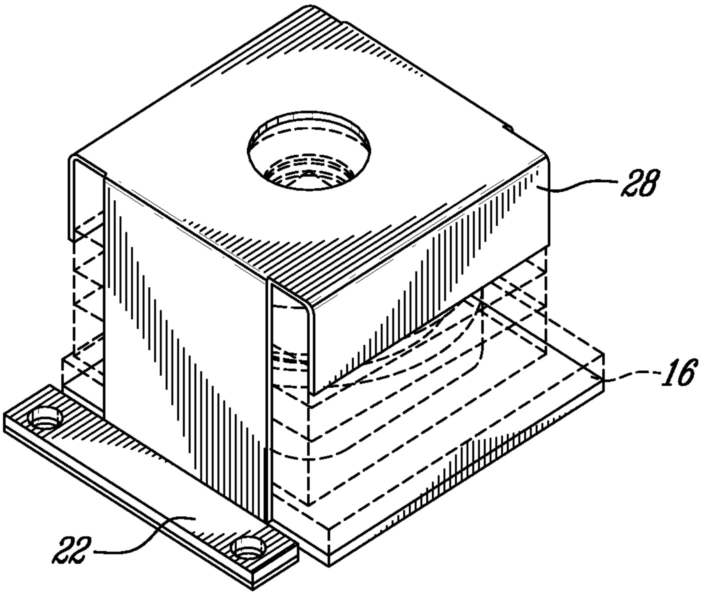

FIG. 4

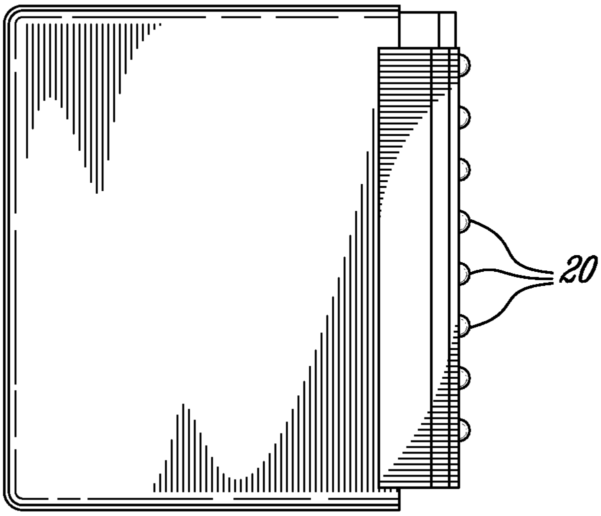

FIG. 5A

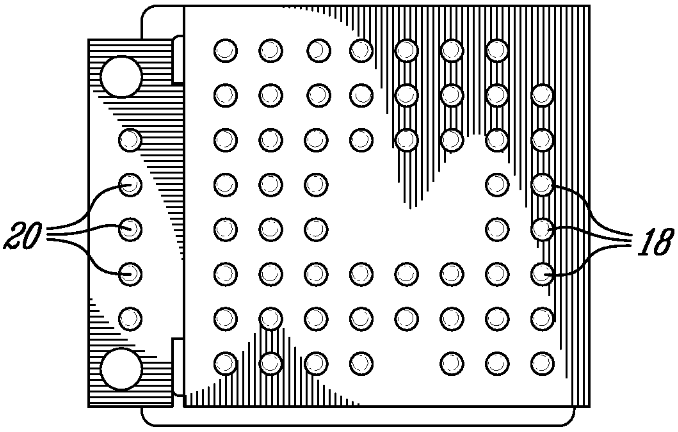

FIG. 5B

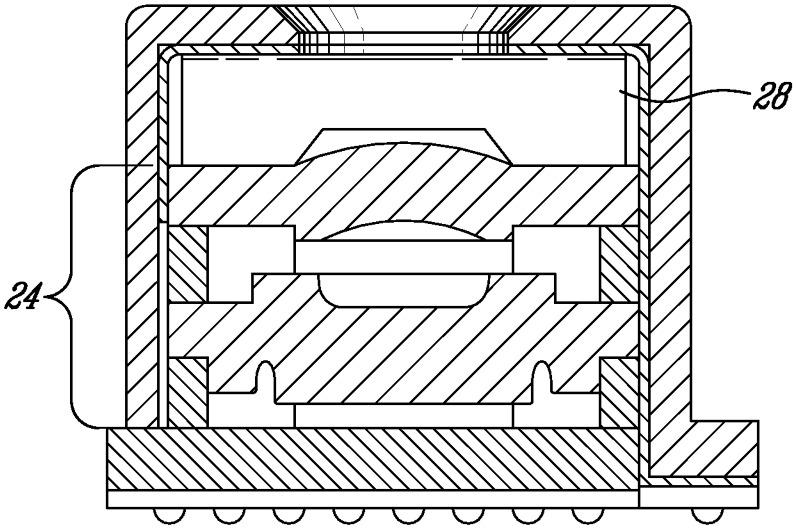

FIG. 6

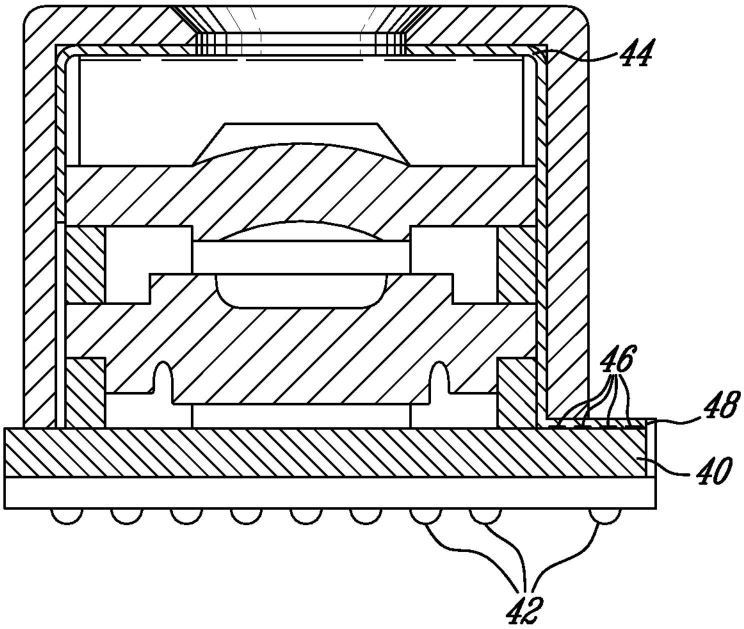

FIG. 7