

WAFER-LEVEL PACKAGE WITH ENHANCED PERFORMANCERelated Applications

5 **[0001]** This application claims the benefit of provisional patent application serial number 62/374,304 filed August 12, 2016, the disclosure of which is hereby incorporated herein by reference in its entirety.

Field of the Disclosure

10 **[0002]** The present disclosure relates to a wafer-level package and a process for making the same, and more particularly to a wafer-level package with enhanced thermal, electrical, and rigidity performance, and a packaging process to enhance thermal, electrical and rigidity performance of a wafer-level package.

Background

15 **[0003]** The wide utilization of cellular and wireless devices drives the rapid development of radio frequency (RF) technologies. The substrates on which RF devices are fabricated play an important role in achieving high level performance in the RF technologies. Fabrications of the RF devices on conventional silicon substrates may benefit from low cost of silicon materials, a large scale capacity
20 of wafer production, well-established semiconductor design tools, and well-established semiconductor manufacturing techniques.

[0004] Despite the benefits of using conventional silicon substrates for the RF device fabrications, it is well known in the industry that the conventional silicon substrates may have two undesirable properties for the RF devices: harmonic
25 distortion and low resistivity values. The harmonic distortion is a critical impediment to achieve high level linearity in the RF devices built over silicon substrates. In addition, the low resistivity encountered in the silicon substrates may degrade quality factors (Q) at high frequencies of microelectromechanical systems (MEMS) or other passive components.

30 **[0005]** Further, high speed and high performance transistors are more densely integrated in RF devices. Consequently, the amount of heat generated

by the RF devices will increase significantly due to the large number of transistors integrated in the RF devices, the large amount of power passing through the transistors, and the high operation speed of the transistors. Accordingly, it is desirable to package the RF devices in a configuration for better heat dissipation.

5 [0006] Wafer-level fan-out (WLFO) packaging technology and embedded wafer-level ball grid array (EWLB) technology currently attract substantial attention in portable RF applications. WLFO and EWLB technologies are designed to provide high density input/output ports (I/O) without increasing the size of a package. This capability allows for densely packaging the RF devices within a single wafer.

10 [0007] To accommodate the increased heat generation of the RF devices, to reduce deleterious harmonic distortion of the RF devices, and to utilize advantages of WLFO/EWLB packaging technologies, it is therefore an object of the present disclosure to provide an improved package design with enhanced performance. Further, there is also a need to enhance the performance of the RF devices without increasing the package size.

Summary

20 [0008] The present disclosure relates to a wafer-level package with enhanced thermal, electrical, and rigidity performance, and a process for making the same. The disclosed wafer-level package includes a first thinned die, a multilayer redistribution structure, a first mold compound, and a second mold compound. The first thinned die includes a first device layer and a first dielectric layer over the first device layer. The first device layer includes a number of first die contacts at a bottom surface of the first device layer. The multilayer redistribution structure includes at least one first support pad, a number of package contacts, and redistribution interconnects. Herein, the first thinned die resides over a top surface of the multilayer redistribution structure. The at least one first support pad is on a bottom surface of the multilayer redistribution structure and vertically aligned with the first thinned die, such that the at least one first support pad is

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placed vertically below the first thinned die. The package contacts are also on the bottom surface of the multilayer redistribution structure. The redistribution interconnects connect the package contacts to certain ones of the first die contacts. The at least one first support pad is electrically isolated from the package contacts. In addition, the first mold compound resides over the multilayer redistribution structure and around the first thinned die, and extends beyond a top surface of the first thinned die to define an opening within the first mold compound and over the first thinned die. The top surface of the first thinned die is exposed at a bottom of the opening. The second mold compound fills the opening and is in contact with the top surface of the first thinned die.

[0009] In one embodiment of the wafer-level package, the at least one first support pad and the package contacts are formed from a common electrically conductive layer.

[0010] In one embodiment of the wafer-level package, a bottom surface of the at least one first support pad and a bottom surface of each package contact are in a same flat plane.

[0011] In one embodiment of the wafer-level package, the multilayer redistribution structure further comprises at least one second support pad on the bottom surface of the multilayer redistribution structure and not placed vertically below the first thinned die. Herein, the at least one second support pad is electrically isolated from the package contacts.

[0012] In one embodiment of the wafer-level package, the at least one first support pad and the at least one second support pad are separate.

[0013] In one embodiment of the wafer-level package, the at least one first support pad and the at least one second support pad are connected together.

[0014] In one embodiment of the wafer-level package, the first thinned die provides a microelectromechanical systems (MEMS) component.

[0015] In one embodiment of the wafer-level package, the first thinned die is formed from a silicon-on-insulator (SOI) structure. The first device layer of the first thinned die is formed from a silicon epitaxy layer of the SOI structure, and

the first dielectric layer of the first thinned die is a buried oxide layer of the SOI structure.

[0016] According to another embodiment, the wafer-level package further includes a second intact die residing over the multilayer redistribution structure.

5 Herein, the second intact die has a second device layer and an intact silicon substrate over the second device layer, and the first mold compound encapsulates the second intact die.

[0017] According to another embodiment, the wafer-level package further includes a third thinned die residing over the multilayer redistribution structure.

10 Herein, the third thinned die has a third device layer and a second dielectric layer over the third device layer. The first mold compound extends beyond a top surface of the third thinned die to define a second opening within the first mold compound and over the third thinned die. The top surface of the third thinned die is exposed at a bottom of the second opening. The second mold compound fills
15 the second opening and in contact with the top surface of the third thinned die.

[0018] In one embodiment of the wafer-level package, the multilayer redistribution structure further comprises at least one second support pad and at least one third support pad on the bottom surface of the multilayer redistribution structure. The at least one second support pad and the at least one third support
20 pad are electrically isolated from the package contacts. The at least one second support pad is not placed vertically below the first thinned die and not placed vertically below the third thinned die. The at least one third support pad is vertically aligned with the third thinned die, such that the at least one third support pad is placed vertically below the third thinned die.

25 **[0019]** In one embodiment of the wafer-level package, the first thinned die provides a MEMS component, the second intact die provides a complementary metal-oxide-semiconductor (CMOS) controller that controls the MEMS component, and the third thinned die is formed from a SOI structure. Herein, the third device layer of the third thinned die is formed from a silicon epitaxy layer of
30 the SOI structure, and the second dielectric layer of the third thinned die is a buried oxide layer of the SOI structure.

[0020] In one embodiment of the wafer-level package, the multilayer redistribution structure further includes at least one structure pad. Herein, the at least one structure pad and the redistribution interconnects are formed from a common electrically conductive layer. The at least one structure pad is vertically below the first thinned die, and electrically isolated from the redistribution interconnects.

[0021] In one embodiment of the wafer-level package, the second mold compound has a thermal conductivity greater than 2 W/m·K.

[0022] In one embodiment of the wafer-level package, the second mold compound has an electrical resistivity greater than 1E6 Ohm-cm.

[0023] In one embodiment of the wafer-level package, the first mold compound is formed from a same material as the second mold compound.

[0024] In one embodiment of the wafer-level package, the first mold compound and the second mold compound are formed from different materials.

[0025] In one embodiment of the wafer-level package, the multilayer redistribution structure is free of glass fiber.

[0026] In one embodiment of the wafer-level package, connections between the redistribution interconnects and the plurality of first die contacts are solder-free.

[0027] In another embodiment, an exemplary wafer-level package includes a first thinned die, a multilayer redistribution structure, a first mold compound, and a second mold compound. The first thinned die includes a first device layer and a first dielectric layer over the first device layer. The first device layer includes a number of first die contacts at a bottom surface of the first device layer. The multilayer redistribution structure includes at least one structure pad, a number of package contacts, and redistribution interconnects. Herein, the first thinned die resides over a top surface of the multilayer redistribution structure. The package contacts are on a bottom surface of the multilayer redistribution structure. The redistribution interconnects connect the package contacts to certain ones of the first die contacts. The at least one structure pad and the redistribution interconnects are formed from a common electrically conductive layer, but the at

least one structure pad is electrically isolated from the redistribution interconnects. The at least one structure pad is placed vertically below the first thinned die. In addition, the first mold compound resides over the multilayer redistribution structure and around the first thinned die, and extends beyond a top surface of the first thinned die to define an opening within the first mold compound and over the first thinned die. The top surface of the first thinned die is exposed at a bottom of the opening. The second mold compound fills the opening and is in contact with the top surface of the first thinned die.

[0028] According to an exemplary process, a mold wafer having a first die and a first mold compound is provided. Herein, the first die includes a first device layer, a first dielectric layer over the first device layer, and a first silicon substrate over the first dielectric layer. The first device layer includes a number of first die contacts at a bottom surface of the first device layer. A top surface of the first die is a top surface of the first silicon substrate and a bottom surface of the first die is the bottom surface of the first device layer. The first mold compound encapsulates the sides and the top surface of the first die, and the bottom surface of the first device layer is exposed. Next, a multilayer redistribution structure is formed underneath the mold wafer. The multilayer redistribution structure includes at least one first support pad, a number of package contacts, and redistribution interconnects. The at least one first support pad is on a bottom surface of the multilayer redistribution structure and vertically aligned with the first die, such that the at least one first support pad is placed vertically below the first die. The package contacts are on the bottom surface of the multilayer redistribution structure and electrically isolated from the at least one first support pad. The redistribution interconnects connect the package contacts to certain ones of the first die contacts. The first mold compound is then thinned down to expose the top surface of the first silicon substrate. The first silicon substrate of the first die is removed substantially to provide a first thinned die and form a first opening within the first mold compound and over the first thinned die. The at least one first support pad is vertically below the first thinned die, and the first thinned die has a top surface exposed at a bottom of the first opening. Lastly, a

second mold compound is applied to substantially fill the opening and directly contact the top surface of the first thinned die.

[0028a] In view of the above, according to an aspect of the present disclosure, there is provided an apparatus. The apparatus comprises: a first thinned die
5 comprising a first device layer and a first dielectric layer over the first device layer, wherein the first device layer comprises a plurality of first die contacts at a bottom surface of the first device layer; a multilayer redistribution structure comprising at least one first support pad, a plurality of package contacts, and redistribution interconnects, wherein: the first thinned die resides over a top
10 surface of the multilayer redistribution structure; the at least one first support pad is on a bottom surface of the multilayer redistribution structure and vertically aligned with the first thinned die, such that the at least one first support pad is placed vertically below the first thinned die; the plurality of package contacts are on the bottom surface of the multilayer redistribution structure; and the
15 redistribution interconnects connect the plurality of package contacts to certain ones of the plurality of first die contacts, wherein the at least one first support pad is not in contact with the plurality of package contacts and the redistribution interconnects, and is electrically isolated from the plurality of package contacts, the redistribution interconnects, and the plurality of first die contacts; a first mold
20 compound residing over the multilayer redistribution structure and around the first thinned die, and extending beyond a top surface of the first thinned die to define an opening within the first mold compound and over the first thinned die, wherein the top surface of the first thinned die is exposed at a bottom of the opening; and a second mold compound filling the opening and in contact with the top surface
25 of the first thinned die.

[0028b] In view of the above, according to another aspect of the present disclosure, there is provided an apparatus. The apparatus comprises: a first thinned die comprising a first device layer and a first dielectric layer over the first device layer, wherein the first device layer comprises a plurality of first die
30 contacts at a bottom surface of the first device layer; a multilayer redistribution structure comprising at least one structure pad, a plurality of package contacts,

and redistribution interconnects, wherein: the first thinned die resides over a top surface of the multilayer redistribution structure; the plurality of package contacts are on a bottom surface of the multilayer redistribution structure; the redistribution interconnects connect the plurality of package contacts to certain ones of the plurality of first die contacts; the at least one structure pad and the redistribution interconnects are formed from a common electrically conductive layer; and the at least one structure pad is vertically below the first thinned die, and electrically isolated from the redistribution interconnects and the plurality of first die contacts; a first mold compound residing over the multilayer redistribution structure and around the first thinned die, and extending beyond a top surface of the first thinned die to define an opening within the first mold compound and over the first thinned die, wherein the top surface of the first thinned die is exposed at a bottom of the opening; and a second mold compound filling the opening and in contact with the top surface of the first thinned die.

15 **[0028c]** In view of the above, according to yet another aspect of the present disclosure, there is provided a method. The method comprises: providing a mold wafer having a first die and a first mold compound, wherein: the first die comprises a first device layer, a first dielectric layer over the first device layer, and a first silicon substrate over the first dielectric layer, wherein the first device layer comprises a plurality of first die contacts at a bottom surface of the first device layer; a top surface of the first die is a top surface of the first silicon substrate and a bottom surface of the first die is the bottom surface of the first device layer; and the first mold compound encapsulates the sides and the top surface of the first die, wherein the bottom surface of the first device layer is exposed; forming a multilayer redistribution structure underneath the mold wafer, wherein: the multilayer redistribution structure comprises at least one first support pad, a plurality of package contacts, and redistribution interconnects; the at least one first support pad is on a bottom surface of the multilayer redistribution structure and vertically aligned with the first die, such that the at least one first support pad is placed vertically below the first die; the plurality of package contacts are on the bottom surface of the multilayer redistribution structure; and

the redistribution interconnects connect the plurality of package contacts to certain ones of the plurality of first die contacts, wherein the at least one first support pad is not in contact with the plurality of package contacts and the redistribution interconnects, and is electrically isolated from the plurality of package contacts, the redistribution interconnects, and the plurality of first die contacts; thinning down the first mold compound to expose the top surface of the first silicon substrate; removing substantially the first silicon substrate of the first die to provide a first thinned die and form an opening within the first mold compound and over the first thinned die, wherein the at least one first support pad is vertically below the first thinned die, and the first thinned die has a top surface exposed at a bottom of the opening; and applying a second mold compound to substantially fill the opening and directly contact the top surface of the first thinned die.

[0029] Those skilled in the art will appreciate the scope of the present disclosure and realize additional aspects thereof after reading the following detailed description of the preferred embodiments in association with the accompanying drawing figures.

Brief Description of the Drawing Figures

[0030] The accompanying drawing figures incorporated in and forming a part of this specification illustrate several aspects of the disclosure, and together with the description serve to explain the principles of the disclosure.

[0031] Figure 1 shows an exemplary wafer-level package according to one embodiment of the present disclosure.

[0032] Figure 2 shows an alternative wafer-level package according to another embodiment of the present disclosure.

[0033] Figure 3 shows an alternative wafer-level package according to another embodiment of the present disclosure.

[0034] Figures 4-18 provide exemplary steps that illustrate a process to fabricate the exemplary wafer-level package shown in Figure 1.

[0035] It will be understood that for clear illustrations, Figures 1-18 may not be drawn to scale.

Detailed Description

5 **[0036]** The embodiments set forth below represent the necessary information
to enable those skilled in the art to practice the embodiments and illustrate the
best mode of practicing the embodiments. Upon reading the following
description in light of the accompanying drawing figures, those skilled in the art
will understand the concepts of the disclosure and will recognize applications of
10 these concepts not particularly addressed herein. It should be understood that
these concepts and applications fall within the scope of the disclosure and the
accompanying claims.

[0037] It will be understood that, although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first element could be termed a second element, and, similarly, a second element could be termed a first element, without departing from the scope of the present disclosure. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0038] It will be understood that when an element such as a layer, region, or substrate is referred to as being "on" or extending "onto" another element, it can be directly on or extend directly onto the other element or intervening elements may also be present. In contrast, when an element is referred to as being "directly on" or extending "directly onto" another element, there are no intervening elements present. Likewise, it will be understood that when an element such as a layer, region, or substrate is referred to as being "over" or extending "over" another element, it can be directly over or extend directly over the other element or intervening elements may also be present. In contrast, when an element is referred to as being "directly over" or extending "directly over" another element, there are no intervening elements present. It will also be understood that when an element is referred to as being "connected" or "coupled" to another element, it can be directly connected or coupled to the other element or intervening elements may be present. In contrast, when an element is referred to as being "directly connected" or "directly coupled" to another element, there are no intervening elements present.

[0039] Relative terms such as "below" or "above" or "upper" or "lower" or "horizontal" or "vertical" may be used herein to describe a relationship of one element, layer, or region to another element, layer, or region as illustrated in the Figures. It will be understood that these terms and those discussed above are intended to encompass different orientations of the device in addition to the orientation depicted in the Figures.

[0040] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the disclosure. As used

herein, the singular forms "a," "an," and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises," "comprising," "includes," and/or "including" when used herein specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0041] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. It will be further understood that terms used herein should be interpreted as having a meaning that is consistent with their meaning in the context of this specification and the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0042] The present disclosure relates to a wafer-level package with enhanced thermal, electrical, and rigidity performance, and a packaging process for making the same. Figure 1 shows an exemplary wafer-level package 10 according to one embodiment of the present disclosure. For the purpose of this illustration, the exemplary wafer-level package 10 includes a thinned silicon-on-insulator (SOI) die 12, a thinned microelectromechanical systems (MEMS) die 14, a complementary metal-oxide-semiconductor (CMOS) controller die 16, a multilayer redistribution structure 18, a first mold compound 20, and a second mold compound 22. In different applications, the wafer-level package 10 may include fewer or more thinned MEMS/SOI dies and may include other dies, such as: thinned integrated passive device dies (not shown). For instance, in some applications, the wafer-level package 10 may only include thinned MEMS dies and CMOS controller dies; and in some applications, the wafer-level package 10 may only include thinned SOI dies.

[0043] In detail, the thinned SOI die 12 includes a first device layer 24 and a first dielectric layer 26 over a top surface of the first device layer 24. The first device layer 24 includes a number of first die contacts 28 at a bottom surface of

the first device layer 24. Herein, the thinned SOI die 12 is formed from an SOI structure, which refers to a structure including a silicon substrate, a silicon epitaxy layer, and a buried oxide layer sandwiched between the silicon substrate and the silicon epitaxy layer. The first device layer 24 of the thinned SOI die 12 is
5 formed by integrating electronic components (not shown) in or on the silicon epitaxy layer of the SOI structure. The first dielectric layer 26 of the thinned SOI die 12 is the buried oxide (BOX) layer of the SOI structure. In addition, the silicon substrate of the SOI structure is removed substantially to complete the thinned SOI die 12 (more details in the following discussion). The first device layer 24
10 has a thickness between 0.1 μm and 50 μm , and the first dielectric layer 26 has a thickness between 10 nm and 2000 nm.

[0044] The thinned MEMS die 14 includes a second device layer 30 and a second dielectric layer 32 over a top surface of the second device layer 30. The second device layer 30 includes a MEMS component (not shown) that is typically
15 a switch and a number of second die contacts 34 at a bottom surface of the second device layer 30. Via-structures (not shown) may be used to connect the MEMS component (not shown) to the second die contacts 34. The second device layer 30 has a thickness between 0.5 μm and 100 μm , and may be formed from a combination of dielectric and metal layers (such as silicon oxide, silicon nitride,
20 aluminum, titanium, copper, or the like). The second dielectric layer 32 has a thickness between 10 nm and 10000 nm, and may be formed from silicon oxide, silicon nitride, or aluminum nitride.

[0045] Notice that the thinned SOI die 12 and the thinned MEMS die 14 are both thinned dies, which have a device layer, a dielectric layer over the device
25 layer, and essentially no silicon substrate over the dielectric layer. Herein, essentially no silicon substrate over the dielectric layer refers to at most 2 μm silicon substrate over the dielectric layer. In desired cases, each thinned die does not include any silicon substrate over the dielectric layer such that a top surface of each thinned die is a top surface of the dielectric layer. For other cases, the
30 top surface of one thinned die may be a top surface of the thin silicon substrate.

[0046] The CMOS controller die 16 includes a third device layer 36 and a silicon substrate 38 over the third device layer 36. The third device layer 36 may include a CMOS controller (not shown) that controls the MEMS component (not shown) within the thinned MEMS die 14, and a number of third die contacts 40 at a bottom surface of the third device layer 36. Via-structures (not shown) may be used to connect the CMOS controller (not shown) to the third die contacts 40. The third device layer 36 has a thickness between 0.1 μm and 50 μm , and may be formed from a combination of dielectric and metal layers (such as silicon oxide, silicon nitride, aluminum, titanium, copper, or the like). The CMOS controller die 16 is an intact die, which includes the intact silicon substrate 38 with a thickness between 25 μm and 250 μm or between 10 μm and 750 μm .

[0047] Herein, the multilayer redistribution structure 18 includes a first dielectric pattern 42 at the top, a number of redistribution interconnects 44, a second dielectric pattern 46, and a number of package contacts 48. In one embodiment, the thinned SOI die 12, the thinned MEMS die 14, and the CMOS controller die 16 reside directly over the multilayer redistribution structure 18. As such, the first device layer 24 of the thinned SOI die 12, the second device layer 30 of the thinned MEMS die 14, and the third device layer 36 of the CMOS controller die 16 are in contact with the first dielectric pattern 42. In addition, the first die contacts 28 at the bottom surface of the first device layer 24, the second die contacts 34 at the bottom surface of the second device layer 30, and the third die contacts 40 at the bottom surface of the third device layer 36 are exposed through the first dielectric pattern 42.

[0048] For the purpose of this illustration, the redistribution interconnects 44 include five first redistribution interconnects 44(1) and one second redistribution interconnect 44(2). In different applications, the redistribution interconnects 44 may include fewer or more first redistribution interconnects 44(1)/second redistribution interconnects 44(2). Each first redistribution interconnect 44(1) connects one package contact 48 to a corresponding one of the first, second, and third die contacts 28, 34, and 40. The second redistribution interconnect 44(2) is used to connect one second die contact 34 to a corresponding third die

contact 40, such that the CMOS controller (not shown) within the CMOS controller die 16 electrically connects the MEMS component (not shown) within the thinned MEMS die 14. Herein, each redistribution interconnect 44 is electrically coupled to at least one of the first, second, and third die contacts 28, 34, and 40 through the first dielectric pattern 42 and extends underneath the first dielectric pattern 42. The connections between the redistribution interconnects 44 and the first, second, and third die contacts 28, 34, and 40 are solder-free.

[0049] The second dielectric pattern 46 is formed underneath the first dielectric pattern 42. The second dielectric pattern 46 partially encapsulates each first redistribution interconnect 44(1). As such, a portion of each first redistribution interconnect 44(1) is exposed through the second dielectric pattern 46. Further, the second dielectric pattern 46 fully encapsulates the second redistribution interconnect 44(2). As such, no portion of the second redistribution interconnect 44(2) is exposed through the second dielectric pattern 46. In different applications, there may be extra redistribution interconnects (not shown) electrically coupled to the redistribution interconnects 44 through the second dielectric pattern 46, and an extra dielectric pattern (not shown) formed underneath the second dielectric pattern 46 to partially encapsulate each of the extra redistribution interconnects.

[0050] In this embodiment, each package contact 48 is on a bottom surface of the multilayer redistribution structure 18 and electrically coupled to a corresponding first redistribution interconnect 44(1) through the second dielectric pattern 46. Consequently, the first redistribution interconnects 44(1) connect the package contacts 48 to certain ones of the first, second, and third die contacts 28, 34, and 40. Herein, the package contacts 48 are separate from each other and extend underneath the second dielectric pattern 46, such that an air gap 50 is formed surrounding each package contact 48. The air gap 50 may extend underneath at least 70% of the thinned SOI die 12 and/ or extend underneath at least 70% of the thinned MEMS die 14.

[0051] In the present disclosure, the multilayer redistribution structure 18 may further include a number of support pads 52 placed on the bottom surface of the

multilayer redistribution structure 18 and within the air gap 50. The support pads 52 and the package contact 48 may be formed from a common electrically conductive layer (like a metal layer), such that each support pad 52 and each package contact 48 have a same thickness protruding from a bottom surface of the second dielectric pattern 46. A bottom surface of each support pad 52 and a bottom surface of each package contact 48 are in a same flat plane. Herein, the support pads 52 are not in contact with and electrically isolated from any package contact 48.

[0052] Notice that the thinned SOI die 12 has a thickness between 0.1 μm and 50 μm , the thinned MEMS die 14 has a thickness 0.5 μm and 100 μm , and the multilayer redistribution structure 18 has a thickness between 2 μm and 300 μm . As such, a first combination of the thinned SOI die 12 and a first portion of the multilayer redistribution structure 18 directly underneath the thinned SOI die 12, or a second combination of the thinned MEMS die 14 and a second portion of the multilayer redistribution structure 18 directly underneath the thinned MEMS die 14 may have a thickness as thin as a few μm . If there are no support pads 52 within a first portion of the air gap 50 that is vertically below the thinned SOI die 12, vertical deformations of the first combination may occur during a molding step (more details are described in the following fabrication process). Similarly, if there are no support pads 52 within a second portion of the air gap 50 that is vertically below the thinned MEMS die 14, vertical deformations of the second combination may occur during the molding step (more details are described in following fabrication process). Without extra support in the first and second portions of the air gap 50, the first combination and the second combination may not endure high vertical molding pressure.

[0053] Herein, the support pads 52 may include first support pads 52(1), second support pads 52(2), and third support pads 52(3). The first support pads 52(1) are on the bottom surface of the multilayer redistribution structure 18 and vertically aligned with the thinned SOI die 12. As such, the first support pads 52(1) are placed vertically below the thinned SOI die 12. The first support pads 52(1) form 'standoffs' within the first portion of the air gap 50 that is vertically

below the thinned SOI die 12. These 'standoffs' provide mechanical support to the thinned SOI die 12 for enduring high molding pressures (more details are described in the following fabrication process). By reducing the distance between the adjacent first support pads 52(1) and /or reducing the distance between the first support pads 52(1) and adjacent package contacts 48, the vertical deformations of the first combination of the thinned SOI die 12 and the first portion of the multilayer redistribution structure 18 may be reduced to an acceptable level. The distance between the adjacent first support pads 52(1) may be between 1 μm and 100 μm , and the distance between the first support pads 52(1) and adjacent package contacts 48 may be between 1 μm and 100 μm . Further, each first support pad 52(1) may have a same or different size, and may have a same or different shape, such as square, rectangular, triangle, and round. Each first support pad 52(1) may be sized between 5 $\mu\text{m} \times 5 \mu\text{m}$ and 100 $\mu\text{m} \times 100 \mu\text{m}$. The first support pads 52(1) are sized and placed to avoid coupling effects.

[0054] The second support pads 52(2) are placed on the bottom surface of the multilayer redistribution structure 18, but not placed vertically below the thinned SOI die 12 or vertically below the thinned MEMS die 14. For instance, the second support pads 52(2) may be vertically below the first mold compound 20 and/or vertically below the CMOS controller die 16. The second support pads 52(2) provide extra mechanical support to the wafer-level package 10 for enduring high molding pressure. The distance between the adjacent second support pads 52(2) may be between 1 μm and 100 μm , and the distance between the second support pads 52(2) and adjacent package contacts 48 may be between 1 μm and 100 μm . Further, each second support pad 52(2) may have a same or different size, and may have a same or different shape, such as square, rectangular, triangle, and round. Each second support pad 52(2) may be sized between 5 $\mu\text{m} \times 5 \mu\text{m}$ and 100 $\mu\text{m} \times 100 \mu\text{m}$. The second support pads 52(2) are sized and placed to avoid coupling effects. In some applications, there may be no second support pads 52(2) (referring to no support pads 52 are vertically below the first mold compound 20 and/or the CMOS controller die 16).

If the first support pads 52(1) are placed at a first average density and the second support pads 52(2) are placed at a second average density, the second average density may be the same or different as the first average density. In this embodiment, the second average density is desired to be no more than the first average density.

5 [0055] The third support pads 52(3) are on the bottom surface of the multilayer redistribution structure 18 and vertically aligned with the thinned MEMS die 14. As such, the third support pads 52(3) are placed vertically below the thinned MEMS die 14. The third support pads 52(3) form 'standoffs' within the
10 second portion of the air gap 50, which is vertically below the thinned MEMS die 14, to provide mechanical support to the thinned MEMS die 14. By reducing the distance between the adjacent third support pads 52(3) and/or reducing the distance between the third support pads 52(3) and adjacent package contacts 48, the vertical deformations of the second combination of the thinned MEMS die
15 14 and the second portion of the multilayer redistribution structure 18 may be reduced to an acceptable level. The distance between the adjacent third support pads 52(3) may be between 1 μm and 100 μm , and the distance between the third support pads 52(3) and adjacent package contacts 48 may be between 1 μm and 100 μm . Further, each third support pad 52(3) may have a same or
20 different size, and may have a same or different shape, such as square, rectangular, triangle, and round. Each third support pad 52(3) may be sized between 5 $\mu\text{m} \times 5 \mu\text{m}$ and 100 $\mu\text{m} \times 100 \mu\text{m}$. The third support pads 52(3) are sized and placed to avoid coupling effects. If the third support pads 52(3) are placed at a third average density, the first average density, the second average
25 density, and the third average density may be the same or different. In this embodiment, the second average density is desired to be no more than the third average density, while the first average density may be essentially equal to the third average density.

30 [0056] Herein, the first support pads 52(1), the second support pads 52(2), and the third support pads 52(3) have no electrical purpose but enhance rigidity of the entire wafer-level package 10. The first support pads 52(1), the second

support pads 50(2), and the third support pads 50(3) are sized and placed to reduce vertical deformations as well as minimize performance impact and comply with manufacturability rules (line, space). In some applications, there may be one continuous first support pad 52(1) (not shown) instead of a number of discrete first support pads 52(1) vertically below the thinned SOI die 12. In some applications, there may be one continuous third support pad 52(3) (not shown) instead of a number of discrete third support pads 52(3) vertically below the thinned MEMS die 14. In some applications, the first, second and third support pads 52(1), 52(2), and 52(3) are connected together as one continuous support pad (not shown), which extends within the air gap 50 and is electrically isolated from any package contact 48.

[0057] Further, the multilayer redistribution structure 18 may be free of glass fiber or glass-free. Herein, the glass fiber refers to individual glass strands twisted to become a larger grouping. These glass strands may then be woven into a fabric. The first dielectric pattern 42 and the second dielectric pattern 46 may be formed of Benzocyclobutene (BCB) or polyimide. The redistribution interconnects 44 may be formed of copper or other suitable metals. The package contacts 48 and the support pads 52 may be formed of at least one of copper, gold, nickel, and palladium.

[0058] The first mold compound 20 resides over a top surface of the multilayer redistribution structure 18, resides around the thinned SOI die 12 and the thinned MEMS die 14, and encapsulates the CMOS controller die 16. Further, the first mold compound 20 extends beyond a top surface of the thinned SOI die 12 to define a first opening 54 within the first mold compound 20 and over the thinned SOI die 12, and extends beyond a top surface of the thinned MEMS die 14 to define a second opening 56 within the first mold compound 20 and over the thinned MEMS die 14. Herein, the top surface of the thinned SOI die 12 is exposed at a bottom of the first opening 54, and the top surface of the thinned MEMS die 14 is exposed at a bottom of the second opening 56.

[0059] The second mold compound 22 substantially fills the first and second openings 54 and 56, and is in contact with the top surface of the thinned SOI die

12 and the top surface of the thinned MEMS die 14. The second mold compound 22 has a thermal conductivity greater than 2 W/m·K or greater than 10 W/m·K, and has an electrical resistivity greater than 1E6 Ohm-cm. In general, the higher the thermal conductivity of the second mold compound 22, the better the thermal performance of the thinned SOI die 12 and the thinned MEMS die 14. Further, the high electrical resistivity of the second mold compound 22 may improve the quality factor (Q) at high frequencies of the MEMS component (not shown) of the thinned MEMS die 14.

[0060] The second mold compound 22 may be formed of thermoplastics or thermoset materials, such as PPS (poly phenyl sulfide), overmold epoxies doped with boron nitride or alumina thermal additives, or the like. In some applications, if the wafer-level package 10 only includes the thinned MEMS die 14 and the CMOS controller die 16, The second mold compound 22 may also be formed from an organic epoxy resin system with a thermal conductivity less than 2 W/m·K. The second mold compound 22 may be formed of the same or different material as the first mold compound 20. However, unlike the second mold compound 22, the first mold compound 20 does not have thermal conductivity or electrical resistivity requirements. In some applications, both the first mold compound 20 and the second mold compound 22 have a thermal conductivity greater than 2 W/m·K. In some applications, the first mold compound 20 has a thermal conductivity less than 2 W/m·K and the second mold compound 22 has a thermal conductivity greater than 2 W/m·K. In some applications, the first mold compound 20 has a thermal conductivity greater than 2 W/m·K and the second mold compound 22 has a thermal conductivity greater than 10 W/m·K. Herein, a portion of the second mold compound 22 may reside over a top surface of the first mold compound 20. Notice that the second mold compound 22 is separated from the CMOS controller die 16 by the first mold compound 20. A top surface of the CMOS controller die 16 is in contact with the first mold compound 20.

[0061] In another embodiment, the multilayer redistribution structure 18 may further include a number of structure pads 58, which are directly underneath the first dielectric pattern 42 and encapsulated by the second dielectric pattern 46, as

illustrated in Figure 2. The structure pads 58 and the redistribution interconnects 44 may be formed from a common electrically conductive layer (like a metal layer), therefore each structure pad 58 and each redistribution interconnect 44 have a same thickness protruding from a bottom surface of the first dielectric pattern 42. Consequently, the thickness of the multilayer redistribution structure 18 will not increase. Herein, the structure pads 58 are not in contact with and electrically isolated from any redistribution interconnect 44.

[0062] The structure pads 58 may include first structure pads 58(1) vertically below the thinned SOI die 12 and second structure pads 58(2) vertically below the thinned MEMS die 14. The first structure pads 58(1) increase the structural stiffness of the multilayer redistribution structure 18 and allow the thinned SOI die 12 to endure high molding pressures. Consequently, the vertical deformations of the first combination of the thinned SOI die 12 and the first portion of the multilayer redistribution structure 18 may be reduced to an acceptable level. The distance between the adjacent first structure pads 58(1) may be between 1 μm and 100 μm , and the distance between the first structure pads 58(1) and adjacent redistribution interconnects 44 may be between 1 μm and 100 μm . Further, each first structure pad 58(1) may have a same or different size, and may have a same or different shape, such as square, rectangular, triangle, and round. Each first structure pad 58(1) may be sized between 5 $\mu\text{m} \times 5 \mu\text{m}$ and 100 $\mu\text{m} \times 100 \mu\text{m}$. The first structure pads 58(1) are sized and placed to avoid coupling effects.

[0063] Similarly, the second structure pads 58(2) increase the structural stiffness of the multilayer redistribution structure 18 and allow the thinned MEMS die 14 to endure high molding pressures. Consequently, the vertical deformations of the second combination of the thinned MEMS die 14 and the second portion of the multilayer redistribution structure 18 may be reduced to an acceptable level. The distance between the adjacent second structure pads 58(2) may be between 1 μm and 100 μm , and the distance between the second structure pads 58(2) and adjacent redistribution interconnects 44 may be between 1 μm and 100 μm . Further, each second structure pads 58(2) may have a same or different size,

and may have a same or different shape, such as square, rectangular, triangle, and round. Each second structure pad 58(2) may be sized between $5\text{ }\mu\text{m} \times 5\text{ }\mu\text{m}$ and $100\text{ }\mu\text{m} \times 100\text{ }\mu\text{m}$. The second structure pads 58(2) are sized and placed to avoid coupling effects. In some applications, there may be one continuous first structure pad 58(1) (not shown) instead of a number of discrete first structure pads 58(1) vertically below the thinned SOI die 12. In some applications, there may be one continuous second structure pad 58(2) (not shown) instead of a number of discrete second structure pads 58(2) vertically below the thinned MEMS die 14.

10 **[0064]** In another embodiment, the multilayer redistribution structure 18 may include the structure pads 58, but not include the support pads 52, as illustrated in Figure 3. Although there is no extra support within the first portion of the air gap 50 that is vertically below the thinned SOI die 12, the first structure pads 58 (1) increase the structural stiffness of the multilayer redistribution structure 18, such that the first combination of the thinned SOI die 12 and the first portion of the multilayer redistribution structure 18 may still be rigid enough to ensure high molding pressures. The vertical deformations of the first combination of the thinned SOI die 12 and the first portion of the multilayer redistribution structure 18 may be reduced to an acceptable level. Similarly, although there is no extra support within the second portion of the air gap 50 that is vertically below the thinned MEMS die 14, the second structure pads 58(1) increase the structural stiffness of the multilayer redistribution structure 18, such that the second combination of the thinned MEMS die 14 and the second portion of the multilayer redistribution structure 18 may still be rigid enough to ensure high molding pressures. The vertical deformations of the second combination of the thinned MEMS die 14 and the second portion of the multilayer redistribution structure 18 may be reduced to an acceptable level.

25 **[0065]** Figures 4-18 provide exemplary steps to fabricate the exemplary wafer-level package 10 shown in Figure 1. Although the exemplary steps are illustrated in a series, the exemplary steps are not necessarily order dependent. Some steps may be done in a different order than that presented. Further,

processes within the scope of this disclosure may include fewer or more steps than those illustrated in Figures 4-18.

[0066] Initially, an adhesive layer 60 is applied on a top surface of a carrier 62 as illustrated in Figure 4. Then, an SOI die 12D, a MEMS die 14D, and the CMOS controller die 16 are attached to the adhesive layer 60 as illustrated in Figure 5. In different applications, there might be fewer or more dies attached to the adhesive layer 60. For instance, in some applications, there may be only the SOI die 12D attached to the adhesive layer 60; and in some applications, there may be only the MEMS die 14D and the CMOS controller die 16 attached to the adhesive layer 60.

[0067] The SOI die 12D includes the first device layer 24, the first dielectric layer 26 over the top surface of the first device layer 24, and a first silicon substrate 64 over the first dielectric layer 26. As such, the bottom surface of the first device layer 24 is a bottom surface of the SOI die 12D, and the backside of the first silicon substrate 64 is a top surface of the SOI die 12D. Herein, the SOI die 12D is formed from an SOI structure, which refers to a structure including a silicon substrate, a silicon epitaxy layer, and a buried oxide layer sandwiched between the silicon substrate and the silicon epitaxy layer. The first device layer 24 of the SOI die 12D is formed by integrating electronic components (not shown) in or on the silicon epitaxy layer of the SOI structure. The first dielectric layer 26 of the SOI die 12D is the buried oxide layer of the SOI structure. The first silicon substrate 64 of the SOI die 12D is the silicon substrate of the SOI structure. The SOI die 12D has a thickness between 25 μm and 250 μm or between 10 μm and 750 μm , and the first silicon substrate 64 has a thickness between 25 μm and 250 μm or between 10 μm and 750 μm , respectively.

[0068] The MEMS die 14D includes the second device layer 30, the second dielectric layer 32 over the top surface of the second device layer 30, and a second silicon substrate 66 over the second dielectric layer 32. As such, the bottom surface of the second device layer 30 is a bottom surface of the MEMS die 14D, and the backside of the second silicon substrate 66 is a top surface of the MEMS die 14D. The MEMS die 14D has a thickness between 25 μm and 300

μm or between $10\ \mu\text{m}$ and $800\ \mu\text{m}$, and the second silicon substrate 66 has a thickness between $25\ \mu\text{m}$ and $300\ \mu\text{m}$ or between $10\ \mu\text{m}$ and $800\ \mu\text{m}$, respectively. In this embodiment, the CMOS controller die 16 may be shorter than the SOI die 12D and the MEMS die 14D. In different applications, the CMOS controller die 16 may be the same height as the SOI die 12D or the MEMS die 14D, or the CMOS controller die 16 may be taller than the SOI die 12D and the MEMS die 14D.

[0069] Next, the first mold compound 20 is applied over the adhesive layer 60 to encapsulate the SOI die 12D, the MEMS die 14D, and the CMOS controller die 16 as illustrated in Figure 6. The first mold compound 20 may be an organic epoxy resin system or the like, which can be used as an etchant barrier to protect the SOI die 12D, the MEMS die 14D, and the CMOS controller die 16 against etching chemistries such as potassium hydroxide (KOH), sodium hydroxide (NaOH), and acetylcholine (ACH). The first mold compound 20 may be applied by various procedures, such as sheet molding, overmolding, compression molding, transfer molding, dam fill encapsulation, or screen print encapsulation. In a typical compression molding, a molding pressure used for applying the first mold compound 20 is between 100 psi and 1000 psi. Since the SOI die 12D, the MEMS die 14D, and the CMOS controller die 16 are relatively thick and the bottom surfaces of the SOI die 12D, the MEMS die 14D, and the CMOS controller die 16 are essentially flat, there may be no vertical deformations occurring to the SOI die 12D, the MEMS die 14D, or the CMOS controller die 16 during this molding step.

[0070] A curing process (not shown) is then used to harden the first mold compound 20. The curing temperature is between $100\ ^\circ\text{C}$ and $320\ ^\circ\text{C}$ depending on which material is used as the first mold compound 20. The adhesive layer 60 and the carrier 62 are then removed to expose the bottom surface of the first device layer 24, the bottom surface of the second device layer 30, and the bottom surface of the third device layer 36 as shown in Figure 7. Removal of the adhesive layer 60 and the carrier 62 may be provided by heating the adhesive layer 60.

[0071] With reference to Figures 8 through 12, the multilayer redistribution structure 18 is formed according to one embodiment of the present disclosure. The first dielectric pattern 42 is firstly formed underneath the SOI die 12D, the MEMS die 14D, and the CMOS controller die 16, as illustrated in Figure 8. As
5 such, the first, second, and third die contacts 28, 34, and 40 are exposed through the first dielectric pattern 42.

[0072] Next, the redistribution interconnects 44 are formed as illustrated in Figure 9. Herein, the redistribution interconnects 44 includes five first redistribution interconnects 44(1) and one second redistribution interconnect
10 44(2). In different applications, the redistribution interconnects 44 may include fewer or more first redistribution interconnects 44(1)/second redistribution interconnects 44(2). The first redistribution interconnects 44(1) are electrically coupled to the first, second, and third die contacts 28, 34, and 40 through the first dielectric pattern 42 and extend underneath the first dielectric pattern 42. The
15 second redistribution interconnect 44(2) is used to connect one second die contact 34 to a corresponding third die contact 40, such that the CMOS controller (not shown) within the CMOS controller die 16 electrically connects the MEMS component (not shown) within the thinned MEMS die 14. The second redistribution interconnect 44(2) may also extend underneath the first dielectric
20 pattern 42. The connections between the redistribution interconnects 44 and the first, second, and third die contacts 28, 34, and 40 are solder-free. If there are the structure pads 58 included in the multilayer redistribution structure 18, the structure pads 58 may be formed simultaneously with the redistribution interconnects 44 from a common electrically conductive layer (not shown).

[0073] The second dielectric pattern 46 is formed underneath the first dielectric pattern 42 to partially encapsulate each first redistribution interconnect 44(1) as illustrated in Figure 10. As such, a portion of each first redistribution interconnect 44(1) is exposed through the second dielectric pattern 46. Further, the second dielectric pattern 46 fully encapsulates the second redistribution
25 interconnect 44(2). As such, no portion of the second redistribution interconnect 44(2) is exposed through the second dielectric pattern 46. If there are the
30

structure pads 58 included in the multilayer redistribution structure 18, the second dielectric pattern 46 fully encapsulates each structure pad 58. As such, no portion of each structure pad 58 is exposed through the second dielectric pattern 46.

5 **[0074]** An electrically conductive layer 68 is then formed as illustrated in Figure 11. The electrically conductive layer 68 may be formed of at least one of copper, gold, nickel, and palladium, and is electrically coupled to each first redistribution interconnect 44(1). The electrically conductive layer 68 extends underneath the second dielectric pattern 46 and has a flat bottom surface. Lastly,
10 the package contacts 48 and the support pads 52 are formed simultaneously by patterning the common electrically conductive layer 68, as illustrated in Figure 12. In different applications, the package contacts 48 and the support pads 52 may not be formed from a common layer and may be formed sequentially (not shown). In any case, the bottom surface of each package contact 48 and the bottom
15 surface of each support pad 52 are in a same flat plane. The support pads 52 are not in contact with and electrically isolated from any package contact 48.

[0075] In this embodiment, each package contact 48 is electrically coupled to a corresponding first redistribution interconnect 44(1) through the second dielectric pattern 46. Consequently, the first redistribution interconnects 44(1)
20 connect the package contacts 48 to certain ones of the first, second, and third die contacts 28, 34, and 40. The support pads 52 are formed within the air gap 50, which is surrounding each package contact 48. However, the support pads 52 are not in contact with and electrically isolated from any package contact 48.

[0076] Herein, the support pads 52 may include the first support pads 52(1),
25 the second support pads 52(2), and the third support pads 52(3). The first support pads 52(1) are placed vertically below the SOI die 12D. The third support pads 52(3) are placed vertically below the MEMS die 14D. The second support pads 52(2) are not placed vertically below the SOI die 12D or vertically below the MEMS die 14D. The second support pads 52(2) may be vertically below the first
30 mold compound 20 and/or vertically below the CMOS controller die 16. If the first support pads 52(1) are formed at a first average density, the second support

pads 52(2) are formed at a second average density, and the third support pads 52(3) are formed at a third average density, the first average density, the second average density, and the third average density may be the same or different. In this embodiment, the second average density is desired to be no more than the first average density or the third average density, while the first average density may be essentially equal to the third average density.

[0077] After the multilayer redistribution structure 18 is formed, the first mold compound 20 is thinned down to expose the first silicon substrate 64 of the SOI die 12D and the second silicon substrate 66 of the MEMS die 14D as shown in

Figure 13. The thinning procedure may be done with a mechanical grinding process. Since the CMOS controller die 16 has a lower height than both the MEMS die 14D and the SOI die 12D, the silicon substrate 38 of the CMOS controller die 16 is not exposed and still encapsulated by the first mold compound 20.

[0078] Next, the first silicon substrate 64 and the second silicon substrate 66 are removed substantially to form a precursor package 70, as illustrated in Figure 14. The removal of the first silicon substrate 64 from the SOI die 12D provides the thinned SOI die 12 and forms the first opening 54 within the first mold compound 20 and over the thinned SOI die 12. The removal of the second silicon substrate 66 from the MEMS die 14D provides the thinned MEMS die 14 and forms the second opening 56 within the first mold compound 20 and over the thinned MEMS die 14. Herein, removing substantially a silicon substrate refers to removing at least 95% of the entire silicon substrate and leaving at most 2 μm silicon substrate. In desired cases, the first and second silicon substrates 62 and 64 are removed completely, such that the first dielectric layer 26 of the thinned SOI die 12 is exposed at the bottom of the first opening 54 and the second dielectric layer 32 of the thinned MEMS die 14 is exposed at the bottom of the second opening 56.

[0079] Removing substantially the first and second silicon substrates 62 and 64 may be provided by an etching process with a wet/dry etchant chemistry, which may be TMAH, KOH, ACH, NaOH, or the like. The first dielectric layer 26

functions as an etching stop to protect the first device layer 24 of the thinned SOI die 12, and the second dielectric layer 32 functions as an etching stop to protect the second device layer 30 of the thinned MEMS die 14. The first mold compound 20 encapsulates and protects the CMOS controller die 16 from the wet/dry etchant chemistry. In some applications, a protection layer (not shown) may be placed at the bottom surface of the multilayer redistribution structure 18 to protect the package contacts 48 from the etchant chemistry. The protection layer is applied before the etching process and removed after the etching process. Further, if the silicon substrate 38 of the CMOS controller die 16 is not encapsulated by the first mold compound 20 (in some application, the CMOS controller die 16 has a same height as or is taller than the SOI die 12D and the MEMS die 14D, the silicon substrate 38 of the CMOS controller die 16 will be exposed during the thinning process), there may be an extra protection layer (not shown) placed over the silicon substrate 38 to protect the CMOS controller die 16 from the etchant chemistry. The extra protection layer is applied before the etching process and removed after the etching process.

[0080] The precursor package 70 may be attached to a rigid carrier 72 via an adhesive material 74, as illustrated in Figure 15. Herein, the rigid carrier 72 may be a photo-transmissive rigid carrier and formed from quartz, fused silica, or sapphire. The adhesive material 74 may be a UV sensitive adhesive tape or film. The package contacts 48 and the support pads 52 may be in contact with the adhesive material 74. The rigid carrier 72 may help assist with mechanical support of the precursor package 70. In some applications, the precursor package 70 may not be attached to the rigid carrier 72 for the following fabrication steps.

[0081] The second mold compound 22 is then applied to substantially fill the first and second openings 54 and 56, as illustrated in Figure 16. Herein, substantially filling an opening refers to filling at least 75% of the entire opening. The second mold compound 22 directly resides over the top surface of the thinned SOI die 12 and the top surface of the thinned MEMS die 14. If there is no first silicon substrate 64 left in the first opening 54 and no second silicon

substrate 66 left in the second opening 56, the second mold compound 22 directly resides over the first dielectric layer 26 and the second dielectric layer 32. In some cases, the second mold compound 22 may further reside over the first mold compound 20.

5 **[0082]** The second mold compound 22 may be formed of thermoplastics or thermoset materials, such as PPS, overmold epoxies doped with boron nitride or alumina thermal additives, or the like. In some applications, the precursor package 70 may only include the thinned MEMS die 14 and the CMOS controller die 16. The second mold compound 22 may also be formed from an organic
10 epoxy resin system with a thermal conductivity less than 2 W/m·K. The second mold compound 22 may be applied by various procedures, such as sheet molding, overmolding, compression molding, transfer molding, dam fill encapsulation, and screen print encapsulation. During the molding process of the second mold compound 22, liquefaction and molding pressure may not be
15 uniform across the entire precursor package 70. The first combination of the thinned SOI die 12 and the first portion of the multilayer redistribution structure 18, and the second combination of the thinned MEMS die 14 and the second portion of the multilayer redistribution structure 18 may suffer more molding pressure than the other portions of the precursor package 70. In a typical
20 compression molding, if the second mold compound 22 is formed of high thermal conductivity materials (≥ 2 W/m·K), a molding pressure and a temperature used for applying the second mold compound 22 is between 250 psi and 1000 psi, and between 100 °C and 350 °C, respectively.

[0083] Notice that the thinned SOI die 12 has a thickness between 0.1 μm
25 and 50 μm , the thinned MEMS die 14 has a thickness 0.5 μm and 100 μm , and the multilayer redistribution structure 18 has a thickness between 2 μm and 300 μm . As such, the first combination of the thinned SOI die 12 and the first portion of the multilayer redistribution structure 18, or the second combination of the thinned MEMS die 14 and the second portion of the multilayer redistribution
30 structure 18 may have a thickness as thin as a few μm . If there is no support within the first portion of the air gap 50 that is vertically below the thinned SOI die

12, the vertical deformations of the first combination may occur at a higher rate. Herein, since the bottom surface of each package contact 48 and the bottom surface of each support pad 52 are in a same flat plane, the first support pads 52(1) form 'standoffs' within the first portion of the air gap 50 to provide

5 mechanical support to the thinned SOI die 12 for enduring high molding pressures. By reducing the distance between the adjacent first support pads 52(1) and /or reducing the distance between the first support pads 52(1) and adjacent package contacts 48, the vertical deformations of the first combination of the thinned SOI die 12 and the first portion of the multilayer redistribution

10 structure 18 may be reduced to an acceptable level.

[0084] Similarly, if there is no support within the second portion of the air gap 50 that is vertically below the thinned MEMS die 14, the vertical deformations of the second combination may occur at a higher rate. Herein, since the bottom surface of each package contact 48 and the bottom surface of each support pad

15 52 are in a same flat plane, the third support pads 52(3) form 'standoffs' within the second portion of the air gap 50 to provide mechanical support to the thinned MEMS die 14 for enduring high molding pressures. By reducing the distance between the adjacent third support pads 52(3) and /or reducing the distance between the third support pads 52(3) and adjacent package contacts 48, the

20 vertical deformations of the second combination of the thinned MEMS die 14 and the second portion of the multilayer redistribution structure 18 may be reduced to an acceptable level.

[0085] Further, the second support pads 52(2) provide mechanical support to the CMOS controller die 16 and/ or the first mold compound 20. The first support

25 pads 52(1), the second support pads 52(2), and the third support pads 52(3) enhance rigidity of the entire wafer-level package 10.

[0086] A curing process (not shown) is followed to harden the second mold compound 22. The curing temperature is between 100 °C and 320 °C depending on which material is used as the second mold compound 22. A top surface of the

30 second mold compound 22 is then planarized to form the wafer-level package 10, as illustrated in Figure 17. If the second mold compound 22 does not cover a top

surface of the first mold compound 20, the top surface of the second mold compound 22 and /or the first mold compound 20 are planarized to be coplanar (not shown). A mechanical grinding process may be used for planarization.

[0087] Lastly, the rigid carrier 72 is debonded from the wafer-level package 10 as illustrated in Figure 18. If the rigid carrier 72 is a photo-transmissive rigid carrier and the adhesive material 74 is a UV sensitive film or tape, the rigid carrier 72 is exposed to a UV environment to achieve the debonding process. The wafer-level package 10 may be marked, diced, and singulated into individual components (not shown).

10 **[0088]** Those skilled in the art will recognize improvements and modifications to the preferred embodiments of the present disclosure. All such improvements and modifications are considered within the scope of the concepts disclosed herein and the claims that follow.

CLAIMS

What is claimed is:

1. An apparatus comprising:
 - a first thinned die comprising a first device layer and a first dielectric layer over the first device layer, wherein the first device layer comprises a plurality of first die contacts at a bottom surface of the first device layer;
 - a multilayer redistribution structure comprising at least one first support pad, a plurality of package contacts, and redistribution interconnects, wherein:
 - the first thinned die resides over a top surface of the multilayer redistribution structure;
 - the at least one first support pad is on a bottom surface of the multilayer redistribution structure and vertically aligned with the first thinned die, such that the at least one first support pad is placed vertically below the first thinned die;
 - the plurality of package contacts are on the bottom surface of the multilayer redistribution structure; and
 - the redistribution interconnects connect the plurality of package contacts to certain ones of the plurality of first die contacts, wherein the at least one first support pad is not in contact with the plurality of package contacts and the redistribution interconnects, and is electrically isolated from the plurality of package contacts, the redistribution interconnects, and the plurality of first die contacts;
 - a first mold compound residing over the multilayer redistribution structure and around the first thinned die, and extending beyond a top surface of the first thinned die to define an opening within the first mold compound and over the first thinned die, wherein the top surface of the first thinned die is exposed at a bottom of the opening; and
 - a second mold compound filling the opening and in contact with the top surface of the first thinned die.

2. The apparatus of claim 1 wherein the plurality of package contacts and the at least one first support pad are formed from a common electrically conductive layer.
3. The apparatus of claim 1 wherein a bottom surface of the at least one first support pad and a bottom surface of each of the plurality of package contacts are in a same flat plane.
4. The apparatus of claim 1 further comprising at least one second support pad on the bottom surface of the multilayer redistribution structure and not placed vertically below the first thinned die, wherein the at least one second support pad is electrically isolated from the plurality of package contacts and the redistribution interconnects.
5. The apparatus of claim 4 wherein the at least one first support pad and the at least one second support pad are separate.
6. The apparatus of claim 4 wherein the at least one first support pad and the at least one second support pad are connected together.
7. The apparatus of claim 1 wherein the first thinned die provides a microelectromechanical systems (MEMS) component.
8. The apparatus of claim 1 wherein the first thinned die is formed from a silicon-on-insulator (SOI) structure, wherein the first device layer of the first thinned die is formed from a silicon epitaxy layer of the SOI structure, and the first dielectric layer of the first thinned die is a buried oxide layer of the SOI structure.
9. The apparatus of claim 1 further comprising a second intact die residing over the top surface of the multilayer redistribution structure, wherein:

- the second intact die has a second device layer and an intact silicon substrate over the second device layer; and
 - the first mold compound encapsulates the second intact die.
10. The apparatus of claim 9 wherein the first thinned die provides a MEMS component and the second intact die provides a complementary metal-oxide-semiconductor (CMOS) controller that controls the MEMS component.
11. The apparatus of claim 9 further comprising a third thinned die residing over the top surface of the multilayer redistribution structure, wherein:
- the third thinned die has a third device layer and a second dielectric layer over the third device layer;
 - the first mold compound extends beyond a top surface of the third thinned die to define a second opening within the first mold compound and over the third thinned die, wherein the top surface of the third thinned die is exposed at a bottom of the second opening; and
 - the second mold compound fills the second opening and is in contact with the top surface of the third thinned die.
12. The apparatus of claim 11 further comprising at least one second support pad and at least one third support pad, wherein:
- the at least one second support pad and the at least one third support pad are on the bottom surface of the multilayer redistribution structure;
 - the at least one second support pad and the at least one third support pad are electrically isolated from the plurality of package contacts and the redistribution interconnects;
 - the at least one second support pad is not placed vertically below the first thinned die and not placed vertically below the third thinned die; and

- the at least one third support pad is vertically aligned with the third thinned die, such that the at least one third support pad is placed vertically below the third thinned die.
13. The apparatus of claim 11 wherein the first thinned die provides a MEMS component, the second intact die provides a CMOS controller that controls the MEMS component, and the third thinned die is formed from an SOI structure, wherein the third device layer of the third thinned die is formed from a silicon epitaxy layer of the SOI structure, and the second dielectric layer of the third thinned die is a buried oxide layer of the SOI structure.
14. The apparatus of claim 1 wherein the multilayer redistribution structure further comprises at least one structure pad, wherein:
- the at least one structure pad and the redistribution interconnects are formed from a common electrically conductive layer; and
 - the at least one structure pad is vertically below the first thinned die, and electrically isolated from the redistribution interconnects and the plurality of first die contacts.
15. The apparatus of claim 1 wherein the second mold compound has a thermal conductivity greater than $2 \text{ W/m}\cdot\text{K}$.
16. The apparatus of claim 1 wherein the second mold compound has an electrical resistivity greater than $1\text{E}6 \text{ Ohm}\cdot\text{cm}$.
17. The apparatus of claim 1 wherein the first mold compound is formed from a same material as the second mold compound.
18. The apparatus of claim 1 wherein the first mold compound and the second mold compound are formed from different materials.

19. The apparatus of claim 1 wherein the multilayer redistribution structure is free of glass fiber.

20. The apparatus of claim 1 wherein connections between the redistribution interconnects and the plurality of first die contacts are solder-free.

21. An apparatus comprising:

- a first thinned die comprising a first device layer and a first dielectric layer over the first device layer, wherein the first device layer comprises a plurality of first die contacts at a bottom surface of the first device layer;
- a multilayer redistribution structure comprising at least one structure pad, a plurality of package contacts, and redistribution interconnects, wherein:
 - the first thinned die resides over a top surface of the multilayer redistribution structure;
 - the plurality of package contacts are on a bottom surface of the multilayer redistribution structure;
 - the redistribution interconnects connect the plurality of package contacts to certain ones of the plurality of first die contacts;
 - the at least one structure pad and the redistribution interconnects are formed from a common electrically conductive layer; and
- the at least one structure pad is vertically below the first thinned die, and electrically isolated from the redistribution interconnects and the plurality of first die contacts;
- a first mold compound residing over the multilayer redistribution structure and around the first thinned die, and extending beyond a top surface of the first thinned die to define an opening within the first mold compound and over the first thinned die, wherein the top surface of the first thinned die is exposed at a bottom of the opening; and

- a second mold compound filling the opening and in contact with the top surface of the first thinned die.
22. A method comprising:
- providing a mold wafer having a first die and a first mold compound, wherein:
 - the first die comprises a first device layer, a first dielectric layer over the first device layer, and a first silicon substrate over the first dielectric layer, wherein the first device layer comprises a plurality of first die contacts at a bottom surface of the first device layer;
 - a top surface of the first die is a top surface of the first silicon substrate and a bottom surface of the first die is the bottom surface of the first device layer; and
 - the first mold compound encapsulates the sides and the top surface of the first die, wherein the bottom surface of the first device layer is exposed;
 - forming a multilayer redistribution structure underneath the mold wafer, wherein:
 - the multilayer redistribution structure comprises at least one first support pad, a plurality of package contacts, and redistribution interconnects;
 - the at least one first support pad is on a bottom surface of the multilayer redistribution structure and vertically aligned with the first die, such that the at least one first support pad is placed vertically below the first die;
 - the plurality of package contacts are on the bottom surface of the multilayer redistribution structure; and
 - the redistribution interconnects connect the plurality of package contacts to certain ones of the plurality of first die contacts, wherein the at least one first support pad is not in contact with the plurality of package contacts and the redistribution interconnects, and is electrically isolated

from the plurality of package contacts, the redistribution interconnects, and the plurality of first die contacts;

- thinning down the first mold compound to expose the top surface of the first silicon substrate;
- removing substantially the first silicon substrate of the first die to provide a first thinned die and form an opening within the first mold compound and over the first thinned die, wherein the at least one first support pad is vertically below the first thinned die, and the first thinned die has a top surface exposed at a bottom of the opening; and
- applying a second mold compound to substantially fill the opening and directly contact the top surface of the first thinned die.