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SEMICONDUCTOR ASSEMBLIES WITH SYSTEMS AND METHODS FOR MANAGING HIGH DIE STACK STRUCTURES

Abstract

A semiconductor device includes a rigid flex circuit that has a first rigid region and a second rigid region that are electrically connected by a flexible portion. A first die is mounted to a first side of the first rigid region. A second die is mounted to a second side of the second rigid region. The first and second sides are on opposite sides of the rigid flex circuit. The flexible portion is bent to hold the first and second rigid regions in generally vertical alignment with each other.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation of U.S. application Ser. No. 18/225,369, filed Jul. 24, 2023; which is a continuation of U.S. application Ser. No. 17/233,129, filed Apr. 16, 2021, now U.S. Pat. No. 11,710,722; each of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD
[0002] The present technology is directed to semiconductor device packaging. More particularly, some embodiments of the present technology relate to structures and techniques for attaching high die stack structures to the substrate.
BACKGROUND
[0003] Packaged semiconductor dies, such as memory chips, microprocessor chips, and imaging chips, typically include a semiconductor die mounted on a substrate and encased in a protective covering. The semiconductor die can include functional features, such as memory cells, processor circuits, and imager devices.
[0004] Market pressures continually drive semiconductor manufacturers to reduce the size of die packages to fit within the space constraints of electronic devices, while also driving them to increase the functional capacity of each package to meet operating parameters. One approach for increasing the processing power of a semiconductor package without substantially increasing the surface area covered by the package (the package's “footprint”) is to vertically stack multiple semiconductor dies on top of one another in a single package. The dies in such vertically-stacked packages can be electrically coupled to each other and/or to a substrate via electrical connectors, interconnects, or other conductive structures. However, as the number of electrical connectors connecting the stacked dies to the substrate increases, the area needed to attach the electrical connector bonds also increases, thus decreasing the room available for other components and connections. Also, it can become increasingly difficult to keep the electrical connectors separate from each other.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0005] Many aspects of the present technology can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale. Instead, emphasis is placed on illustrating the principles of the present technology.
[0006] FIG. **1**A is a cross-sectional view of a plurality of die stacks that are attached to a rigid flex circuit in accordance with embodiments of the present technology.
[0007] FIG. **1**B illustrates top and bottom views of the rigid flex circuit with the components of FIG. **1**A in accordance with embodiments of the present technology.
[0008] FIG. **1**C is a cross-sectional view of the die stack assembly of FIG. **1**A that has been bent to vertically align the die stacks in a vertically aligned assembly in accordance with embodiments of the present technology.
[0009] FIG. **1**D shows a cross-sectional view of the die stack assembly of FIG. **1**C that has been

encapsulated in a molded material in accordance with embodiments of the present technology.
[0010] FIG. **2** is a cross-sectional view of a rigid flex circuit in accordance with embodiments of the present technology.
[0011] FIG. **3** is another cross-sectional view of a vertically aligned assembly including a plurality of die stacks and a rigid flex circuit in accordance with embodiments of the present technology.
[0012] FIG. **4**A is a cross-sectional view of a die stack and a controller die mounted on a rigid flex circuit in accordance with embodiments of the present technology.
[0013] FIG. **4**B is a cross-sectional view of the assembly of FIG. **4**A that has been bent to position the die stack over the controller die in accordance with embodiments of the present technology.
[0014] FIG. **4**C is a cross-sectional view of the vertically aligned assembly of FIG. **4**B that has been mounted to a substrate in accordance with embodiments of the present technology.
[0015] FIG. **4**D is a cross-sectional view of similar components as were used in FIG. **4**A that are mounted on opposing sides of a rigid flex circuit in accordance with embodiments of the present technology.
[0016] FIG. **5**A is a cross-sectional view illustrating the use of a rigid flex circuit in side-by-side or adjacent die stack structures in accordance with embodiments of the present technology.
[0017] FIG. **5**B is a cross-sectional view of the die stack assembly of FIG. **5**A that has been bent and attached to the substrate and another die stack in accordance with embodiments of the present technology.
[0018] FIG. **5**C illustrates top and bottom views of the rigid flex circuit with the components of FIG. **5**A in accordance with embodiments of the present technology.
[0019] FIGS. **6**A-**6**C show a top-down view of a process for fabricating multiple die stack assemblies in accordance with embodiments of the present technology.
[0020] FIG. **7** is a flow chart illustrating a method of making a semiconductor device assembly in accordance with an embodiment of the present technology.
[0021] FIG. **8** is a schematic view showing a system that includes a semiconductor device assembly configured in accordance with an embodiment of the present technology.

DETAILED DESCRIPTION

[0022] Specific details of several embodiments of semiconductor devices are described below. In some embodiments, a plurality of die stacks can be mounted (e.g., attached) to rigid regions of a rigid flex circuit. As described herein, a die stack can include a single die or more than one die. The rigid flex circuit can be a laminated structure that includes one or more inner layers that can convey signals. Electrical connectors (e.g., bond wires, solder interconnects, etc.) can connect some of the dies within a die stack to each other and to a wire bond connection on the rigid flex circuit that is in communication with an appropriate signal conveying layer. The rigid regions of the rigid flex circuit can alternate with flexible portions that allow the rigid flex circuit to be bent, such as by flexing the flexible portions approximately 180 degrees, to generally vertically align at least some of the attached die stacks with each other. In some cases, a spacer (e.g., attached to a die stack and/or the rigid flex circuit) can be used to separate a top side of a die stack or other component from the rigid flex circuit when the assembly is generally or approximately in vertical alignment. Either one of the die stacks or one of the rigid regions of the vertically aligned assembly can be attached to a substrate. Electrical connectors can connect the rigid flex circuit and the substrate to convey the signals associated with the plurality of die stacks to and/or from the substrate.
[0023] Using the rigid flex circuit to form the vertically aligned assembly of die stacks allows shorter wires to be used which can contribute to a cost benefit. The shorter wires can also reduce common wire sweeping and/or shorting issues that can occur during the assembly process. In addition, fewer individual electrical connectors need to be connected to the substrate. Therefore, less space is needed on the substrate for electrical connection and more components can be included within the same footprint. An additional benefit can be realized by applying impedance control for differential signal/high speed signal on the rigid flex circuit to improve signal integrity

by reducing wire to wire signal cross-talk and interference.

[0024] In some cases, other components, such as, but not limited to, a controller die, can be mounted to a rigid region of the rigid flex circuit. The controller die can be molded after attachment or pre-molded. A vertically aligned assembly can be formed by bending one or more flexible portions to position die stack(s) attached to the rigid flex circuit over the controller die. In other embodiments, the rigid flex circuit can be used in side-by-side configurations wherein one or more dies stacks attached to the rigid flex circuit can be positioned over a die stack or other component mounted on the substrate proximate to the rigid flex circuit. This can provide increased capacity within the same footprint by utilizing open space above mounted components, and/or increasing capacity while keeping the overall height of die stacks and/or vertically aligned assemblies within desired limits and/or ranges.

[0025] In some embodiments, the die stacks can be formed on the rigid flex circuit, while in other embodiments, the die stacks can be pre-formed and then mounted on the rigid flex circuit. The electrical connections between the dies, the die stacks, and the rigid flex circuit can be accomplished prior to bending the rigid flex circuit, or iteratively, such as between different multiple bending operations. Some of the die stacks and/or components can be attached to a first side of the rigid flex circuit and then other die stacks and/or components attached to a second side of the rigid flex circuit. In this example, a jig may be used to “flip” one or more rigid flex circuits from one side to the other.

[0026] A person skilled in the relevant art will recognize that, unless the context indicates otherwise, structures disclosed herein can be formed using conventional semiconductor manufacturing techniques. Materials can be deposited, for example, using chemical vapor deposition, physical vapor deposition, atomic layer deposition, plating, electroless plating, spin coating, and/or other suitable techniques. Similarly, materials can be removed, for example, using plasma etching, wet etching, chemical-mechanical planarization, or other suitable techniques.

[0027] Numerous specific details are disclosed herein to provide a thorough and enabling description of embodiments of the present technology. A person skilled in the art, however, will understand that the technology may have additional embodiments and that the technology may be practiced without several of the details of the embodiments described below with reference to FIGS. **1**A-**6**C. For example, some details of semiconductor devices and/or packages well known in the art have been omitted so as not to obscure the present technology. In general, it should be understood that various other devices and systems in addition to those specific embodiments disclosed herein may be within the scope of the present technology.

[0028] As used herein, the terms “vertical,” “lateral,” “upper,” “lower,” “above,” and “below” can refer to relative directions or positions of features in the semiconductor devices in view of the orientation shown in the Figures. For example, “upper” or “uppermost” can refer to a feature positioned closer to the top of a page than another feature. These terms, however, should be construed broadly to include semiconductor devices having other orientations, such as inverted or inclined orientations where top/bottom, over/under, above/below, up/down, and left/right can be interchanged depending on the orientation.

[0029] FIGS. **1**A-**1**D illustrate views of semiconductor dies attached to a rigid flex circuit in accordance with embodiments of the present technology. In particular, FIG. **1**A illustrates a side cross-sectional view of four die stacks attached to a rigid flex circuit (e.g., rigid flex printed circuit board) and FIG. **1**B shows top and bottom views of the rigid flex circuit with components attached. FIG. **1**C illustrates a side cross-sectional view of the die stacks that form a vertically aligned assembly after the rigid flex circuit has been bent in accordance with embodiments of the present technology, and FIG. **1**D shows a single die attached to each rigid region of the rigid flex circuit.

[0030] Referring to FIG. **1**A, rigid flex circuit **106***a* includes a plurality of rigid regions **120***a-d* alternating with one or more flexible portions **122***a-c*. The flexible portions **122** electrically connect adjacent rigid regions **120**. Semiconductor device **100***a* can be bent to form a die stack assembly

that includes first die stack **102***a* and third die stack **102***c* mounted or connected on a first side **104***a* of the rigid flex circuit **106***a*. Second die stack **102***b* and fourth die stack **102***d* are mounted or connected on a second side **108***a* of the rigid flex circuit **106***a*. The die stacks **102** are mounted to the rigid regions **120** of the rigid flex circuit **106***a*. Therefore, as shown, adjacent die stacks **102** are attached to alternating or opposite sides of the rigid flex circuit **106***a*. Although four die stacks **102** are shown, it should be understood that more or less die stacks **102** may be attached to the rigid flex circuit **106***a*, such as two die stacks **102**, three die stacks **102**, or more than four die stacks **102**.
[0031] In some embodiments, the die stacks **102** can be formed on the rigid flex circuit **106***a* by attaching a first die **110** to the rigid region **120** of the rigid flex circuit **106***a*, a second die **110** over at least a portion of the exposed side of the first die **110**, and so on. Die attach film or other known materials and methods may be used. The first die stack **102***a* includes individual semiconductor dies **110***a-h* that are vertically stacked in a shingled or stepped configuration in which each die **110** is offset horizontally from the adjacent die **110**. For example, FIG. **1**A depicts the die stacks **102** in a configuration that may be referred to as "reverse shingle on shingle", wherein the dies **110***a-d* are stepped in a first horizontal direction (e.g., first shingle) and the dies **110***e-h* are stepped in a second horizontal direction that is opposite to the first horizontal direction (e.g., second shingle). It should be understood that the die stacks **102** can be formed by aligning the individual dies **110** such that none or some of the dies **110** are shingled with respect to other dies **110** within the same die stack **102**. The dies **110** can be memory die, such as a NAND die, an SRAM die, or other semiconductor dies. Also, although eight dies **110** are illustrated in each of the die stacks **102**, more or less dies **110** can be included based on system requirements. For example, as discussed below in FIG. **1**D, a single die **110** can be attached to each of the rigid regions **120**. In some cases, not every rigid region may have a die **110** attached to it.
[0032] The shingled or stepped configuration allows for electrical interconnections to be accomplished between adjacent dies **110** in the die stack **102**, which shortens the electrical connector lengths and minimizes the number of electrical connections made to either the rigid flex circuit **106***a* or a substrate (both discussed further below). Therefore, two or more dies **110** in a die stack **102** can be electrically connected to each other and then to the rigid flex circuit **106***a* through one or a reduced number of electrical connectors, eliminating some bond connections to the rigid flex circuit **106***a* (or substrate). The bond pads (shown in FIG. **2**) on the rigid flex circuit **106***a* are connected to one or more communication layers within the rigid flex circuit **106***a*.
[0033] A plurality of electrical connectors **112***a-d* (e.g., wire bonds) couple the dies **110***a-d* to each other and to a bond pad (not shown for purposes of clarity) on the rigid flex circuit **106***a* to route signals (e.g., control signals, power signals, test signals, etc.) between these components. In some embodiments, the ends of each electrical connector **112** are attached to respective bond pads on the corresponding dies **110** (not shown for purposes of clarity). Therefore, instead of requiring separate electrical connectors **112** to electrically connect each of the dies **110***a-d* to the rigid flex circuit **106***a*, the single electrical connector **112***d* conveys the signals for the four dies **110***a-d*. The four dies **110***e-h* are similarly connected with electrical connectors **112***f-i*, and the electrical connector **112***i* extends from the die **110***e* to the rigid flex circuit **106***a*. The die stacks **102***b-d* are similarly connected.
[0034] Each of the die stacks **102** has a top side **114** (e.g., an exposed side) and a bottom side **116**. A surface of the die **110** that is attached to the rigid flex circuit **106***a* is the bottom side **116** and a surface of the die **110** on the opposite side of the die stack **102** is the top side **114**. The top sides **114***a-d* and the bottom sides **116***a-d* of the die stacks **102***a-d* are indicated.
[0035] Inert spacers **118***a-c* can be attached to the rigid flex circuit **106***a* to provide a mechanical and electrical separation between the rigid flex circuit **106***a* and a die stack **102** when the rigid flex circuit **106***a* is bent to position the die stacks **102** into vertical alignment. The spacer can be attached using die attach film and/or other known materials and methods. The spacers **118***a* and **118***c* are positioned on the rigid regions **120** on the second side **108***a* of the rigid flex circuit **106***a*

opposite the first and third die stacks **102***a* and **102***c*, respectively. The spacer **118***b* is positioned on the rigid region **120** of the first side **104***a* of the rigid flex circuit **106***a* opposite the second die stack **102***b*. In some embodiments, the spacer **118** can be a “blank” substrate that does not include semiconductor components and is formed from, for example, substrate materials, such as silicon, glass, ceramic, and/or other suitable materials.

[0036] FIG. **1**B shows a top view **130***a* and a bottom view **132***a* of the semiconductor device **100***a* of FIG. **1**A. The top and bottom views **130***a* and **132***a* correspond to the first and second sides **104***a* and **108***a*, respectively, of the rigid flex circuit **106***a*. The rigid regions **120** and flexible portions **122** are indicated, as well as the die stacks **102***a-d* and the spacers **118***a-c* that are mounted or connected to the first sides **104***a* and second sides **108***a* of the rigid regions **120**.

[0037] The rigid flex circuit **106***a* has length L**1** and width W**1** dimensions configured to accommodate the size and number of die stacks **102** and/or other components that are attached to the rigid regions **120**, and the length(s) needed for bending the flexible portions(s) **122** when vertically aligning the die stacks **102**. More die stacks **102** can be added to the same rigid flex circuit **106***a* by extending the alternating pattern of rigid regions **120** and flexible portions **122**. For example, to maintain the same scheme for folding and attaching the vertically aligned die stacks **102** to the substrate as discussed below, an even number of die stacks **102** would be added. In other examples, a non-even number of die stacks **102** can be added.

[0038] Each of the rigid regions **120** has a length L**2** and width W**2** (indicated on the rigid region **120***d*). The length L**2** and width W**2** of the other rigid regions **120***a-c* may be the same or different than the rigid region **120***d*. The spacers **118***a-c* as shown have a smaller footprint than the width W**2** and length L**2** of their corresponding rigid regions **120***a-c*. The die stacks **102***a-d* also have a smaller footprint than at least the length L**2** of their corresponding rigid region **120**, leaving edge regions **134** (indicated on rigid region **120***a* as edge regions **134***a* and **134***b*). The edge regions **134** include a plurality of bond pads **136** (indicated on edge region **134***a* as bond pads **136***a-h*) for electrically connecting the electrical connectors **112** (shown in FIG. **1**A) from the dies **110**. Although the die stacks **102** and spacers **118** are shown as geometrically being within the length L**2** and width W**2** dimensions of the rigid regions **120**, the components may extend beyond one or more edges of the rigid regions **120**.

[0039] Each of the flexible portions **122** has a length L**3** that is based on a height of the die stack **102** and/or spacer **118** and/or component that the flexible portion **122** extends alongside when the rigid flex circuit **106** is bent. Also, the length L**3** of the flexible portions **122** can vary.

[0040] Returning to FIG. **1**A, once the die stacks **102** and the spacers **118** are attached to the rigid flex circuit **106***a* and the electrical connectors **112** have been attached as needed, the rigid flex circuit **106***a* can be bent to bring the die stacks **102** into generally vertical alignment to form the die stack assembly. For example, the flexible portion **122***c* of the rigid flex circuit **106***a* can be bent in the direction of arrow **124***c* to vertically align the die stack **102***d* with the die stack **102***c*. In other words, the flexible portion **122***c* can be flexed through about 180 degrees to hold the rigid regions **120***c-d* in generally vertical alignment with each other. The top side **114***d* (e.g. exposed side) of the die stack **102***d* can be in mechanical connection with (e.g., touching and/or adhered to) the spacer **118***c*. The flexible portion **122***b* of the rigid flex circuit **106***a* can then be bent in the direction of arrow **124***b* to vertically align the die stacks **102***c-d* with the die stack **102***b*, thus aligning the rigid regions **120***b-d*. The top side **114***c* of the die stack **102***c* can be in mechanical connection with the spacer **118***b*. The flexible portion **122***a* of the rigid flex circuit **106***a* can be bent in the direction of arrow **124***a* to vertically align the die stacks **102***b-d* with the die stack **102***a*, thus also aligning the rigid regions **120***a-d*. The top side **114***b* of the die stack **102***b* can be in mechanical connection with the spacer **118***a*. It should be understood that the flexible portions **122***a-c* of the rigid flex circuit **106***a* can be bent in different orders to align the die stacks **102***a-d.*

[0041] Additionally, a space may be maintained between the top sides **114** (e.g. exposed sides) of the dies **110** or the die stacks **102** and the spacers **118** and/or rigid regions **120** when the rigid regions **120** are held generally in vertical alignment with each other. It should be understood that the embodiments discussed herein are not limited to all of the rigid regions **120** and the die stacks **102** and/or dies **110** mounted thereon being in perfect vertical alignment, and that embodiments are contemplated wherein some offset may be present between these features.

[0042] The vertically aligned die stacks **102***a-d* form a vertically aligned assembly **140***a* that can be attached to a substrate **142** as shown in FIG. **1**C. The substrate **142** can be a semiconductor substrate (e.g., a silicon substrate, a gallium arsenide substrate, an organic laminate substrate, etc.) or other suitable material known in the art. In this example, the rigid region **120***d*, as seen in the top view **130***a* of FIG. **1**B, is attached to the substrate **142**, such as by using die attach film or other known materials and methods. As seen in this side cross-sectional view, the length L**2** of the rigid regions **120** extend beyond the width of the die stacks **102**, and the length L**3** of the flexible portions **122** extend approximately the height of the associated die stack **102** and the spacer **118**.

[0043] After the vertically aligned assembly **140***a* is attached to the substrate **142**, electrical connection can be made between the rigid flex circuit **106***a* and the substrate **142**. Wire bond keep-out area **144** is shown on the substrate **142** proximate the vertically aligned assembly **140***a*. Electrical connector **112***e* extends to a wire bond connection point **146***a*, such as a ball grid array (BGA). After the electrical connections have been made between the vertically aligned assembly **140***a* and the substrate **142**, an encapsulant or molding material **148** can then be formed around the die stacks **102** and electrical connectors **112** of the vertically aligned assembly **140***a* as shown in FIG. **1**D to provide structural integrity and environmental sealing therefor. A plurality of solder balls **150** can be formed on an opposite side **152** of the substrate **142**. The solder balls **150** can connect to a variety of conductive features (not shown) formed within the substrate **142**, such as internal contacts, vias, and traces. One or more of these conductive features can provide electrical connections (e.g., power, ground, and signals) to the wirebond connection point **146***a*, for example.

[0044] Although in the foregoing example embodiments, semiconductor device assemblies have been illustrated and described as including die stacks **102** disposed over four rigid regions **120** of a rigid flex circuit **106**, in other embodiments of the present technology different numbers of dies (e.g., 1, 2, 3, 5, 6, 7, 8, etc.) can be provided on each of any number of rigid regions **120** (e.g., 2, 3, 5, 6, 7, 8, etc.) of a rigid flex circuit **106**.

[0045] Technical advantages, such as smaller wire bond keep-out areas **144** and shorter electrical connectors **112** are realized when using the rigid flex circuit **106***a* to form stacked die structures such as the vertically aligned assembly **140***a*. Referring to the die stack **102***a* in FIG. **1**C, the electrical connectors **112***f-h* connect the dies **110***e-h*, and the electrical connector **112***i* provides the electrical connection for all of the dies **110***e-h* to the rigid flex circuit **106***a*. If the vertically aligned assembly **104***a*, including the 32 dies **110**, did not include the rigid flex circuit **106***a*, the electrical connector **112***i* would instead extend from the die **110***e* to the substrate **142**. This results in long electrical connectors **112** that are difficult to attach to the substrate **142**, and each electrical connector **112** needs space to be attached without interference from another electrical connector **112**. Using the rigid flex circuit **106***a* minimizes the amount of space needed to bond electrical connectors **112**, and available space on the substrate **142** is increased to allow additional passive and/or active components to be mounted. In other words, the footprint required on the substrate **142** is reduced while capacity is increased when the rigid flex circuit **106***a* is used to form the vertically aligned assembly **140***a*.

[0046] For example, a stacked die structure using 16 dies **110** without the rigid flex circuit **106***a* may have a wire bond keep-out area **144** of approximately 600 microns (e.g. micrometer) and have electrical connectors **112** that extend approximately 1.5 millimeters (mm). A stacked die structure using 32 dies **110** without the rigid flex circuit **106***a* may have a wire bond keep-out area **144** of approximately 1200 microns and have electrical connectors **112** that extend approximately 3 mm. In some embodiments, the wire bond keep-out area **144** in FIG. **1**C, for the vertically aligned assembly **140***a* that has 32 dies **110**, can be approximately 600 microns, or about the same size as a stacked die structure using 16 dies **110**. In addition, the length of the electrical connector **112** can be reduced to approximately 1 mm. It should be understood that these measurements are examples only, and many factors, such as thickness and number of dies **110**, can change the length of electrical connectors **112**.

[0047] FIG. **2** illustrates a side cross-sectional view of the rigid flex circuit **106***a* that includes a plurality of layers in accordance with embodiments of the present technology. One rigid region **120** and one flexible portion **122** are shown. The rigid flex circuit **106***a* is a stack and/or laminate of layers. The rigid and flexible portions **120**, **122** can include different layers depending upon the functionality needed.

[0048] The rigid flex circuit **106***a* shown in FIG. **2** is exemplary only. The number and configuration of layers can be determined based on the application. The size or number of layers can be increased to increase signal capacity. The layers of the rigid flex circuit **106***a* and the communication capacity can be custom designed for the application, such that different rigid flex circuits **106** can be used for different applications.

[0049] As shown, the rigid flex circuit **106***a* includes soldermask layers **200***a-b*, copper layers **202***a-d*, FR4 layers **204***a-b*, prepreg layers **206***a-b*, and polyimide core layer **208**. The soldermask layers **200***a-b* can provide rigidity to the rigid region **120**. Additional and/or different layers can extend out of the rigid region **120** to form the flexible portion **122**. For example, polymide coverlay **210***a-b*, coverlay adhesive **212***a-b*, copper layer **202***e-f*, and the polyimide core layer **208**. The polyimide core layer **208** can provide structure while allowing the flexible portion **122** to flex.

[0050] In some embodiments, an opening **214** within an outer layer such as the soldermask **200***a* can expose a bond pad **136***i* or other connection point for connecting a wire bond to the rigid flex circuit **106***a*. The bond pad **136***i* can connect, for example, to one or more of the copper layers **202***e-f* through via(s) (not shown). A via can extend from an outer layer to an inner layer, and can permit communication between two or more layers. The copper layers **202***e-f*, or other appropriate layers, can be referred to as interconnect layers. In some cases, the copper layers **202***e-f* can be patterned with traces of copper (or other conductive material) that are separates from each other to keep signals separate where appropriate. In other cases, some or all of a copper layer **202***e-f* can form a ground plane. The copper layers **202***e-f* (e.g., interconnect layers) can convey signals between the die stacks **102** and/or other components mounted to the rigid flex circuit **106**, and/or a collection area (not shown) of the rigid flex circuit **106***a*. One or more electrical connectors can be connected to the collection area to convey the signals to and/or from the substrate **142**. This provides the advantage of a reduced area size of the substrate **142** that is needed to provide interconnection with the die stacks **102**.

[0051] FIG. **3** illustrates another vertically aligned assembly **140***b* formed in accordance with embodiments of the present technology. The die stacks **102***e-g* and the spacers **118***d-f* are attached to the rigid flex circuit **106***b* as discussed with respect to FIG. **1**A to form the semiconductor device **100***b*. Therefore, the rigid flex circuit **106***b* conveys the signals between the die stacks **102***e-g* and the substrate **142**. In comparison with FIG. **1**C, the rigid flex circuit **106***b* is not between fourth die stack **102***h* and the substrate **142**, thus lowering the overall height of the vertically aligned assembly **140***b*. This can provide the advantage of allowing one or more additional dies **110** to be added to the vertically aligned assembly **140***b*, increasing overall capacity of the semiconductor package.

[0052] The die stack **102***h* can be attached to the substrate **142**, such as with die attach film. In some embodiments, the die **110***i* can be attached to the substrate **142** and subsequent dies **110** attached to form the reverse shingle on shingle configuration of the die stack **102***h*. In other embodiments, the die stack **102***h* can be formed separately and then attached to the substrate **142**. Once the die stack **102***h* is attached to the substrate **142**, the electrical connectors **112** can be connected between the dies **110***i-l* and between the dies **110***m-p*. The electrical connector **112***j* is connected to the substrate **142** at wire bond connection point **146***b* and conveys signals between the four dies **110***m-p*, which are connected together, and the substrate **142**. The electrical connector **112***k* is connected to the substrate **142** at wire bond connection point **146***c* and conveys signals between the four dies **110***i-l*, which are connected together, and the substrate **142**.

[0053] The rigid flex circuit **106***b* can be positioned over the die stack **102***h* so that the spacer **118***f* is in communication with the top side of the die stack **102***h*. In some cases, the spacer **118***f* may be adhered to the die stack **102***h*. The rigid flex circuit **106***b* can have a connection pad **302** that connects one or more electrical connectors of the rigid flex circuit **106***b* with the substrate **142** at wire bond connection point **146***d*. In some cases, a reflow operation can be used to reflow the solder, which may be present on one or both of the connection pad **302** and wire bond connection point **146***d*, to attach the rigid flex circuit **106***b* to the substrate **142**.

[0054] In other embodiments, one or more different components (e.g., active and/or passive components, shorter or taller die stack, etc.) may be attached to the substrate **142** instead of the die stack **102***h*. The die stack assembly can then be positioned over the one or more different components.

[0055] In both of the embodiments shown in FIGS. **1**C and **3**, a technical advantage is realized as less space on the substrate **142** is needed to interconnect the die stacks **102** with the substrate **142**, saving room for additional components. Also, fewer electrical connectors **112** are needed, which increases the ease of attaching the electrical connectors **112** to the substrate **142** and decreases the problem of electrical connectors **112** interfering with each other.

[0056] In some cases, it can be desirable to lower the height of one or more die stacks **102** because A) the die stack **102** is too high for the package, B) to more evenly balance the height of adjacent die stacks **102**, C) to minimize signal communication in the substrate **142**, and/or D) to incorporate additional components. FIG. **4**A shows one die stack **102***i* and a controller die **400***a* attached or connected to rigid regions **120***e* and **120***f*, respectively, of the rigid flex circuit **106***c* in accordance with embodiments of the present technology. The controller die **400***a* (e.g., a microcontroller) can be configured to control the operations of at least the dies **110** of the die stack **102***i* through the rigid flex circuit **106***c*.

[0057] The rigid flex circuit **106***c* can include rigid regions **120***e-g* that alternate with flexible portions **122***d-e*. The rigid region **120***f* can be generally or approximately the same length as the rigid regions **120***e* and **120***g*.

[0058] The die stack **102***i* can be mounted on the rigid region **120***e* as previously discussed, and electrical connectors **112** attached so that the dies **110** are connected to each other. Electrical connector **112***l* and/or other connectors conveys the signals to/from one of the dies **110** and the rigid flex circuit **106***c* at wire bond **146***e*.

[0059] The controller die **400***a* can be mounted to the rigid region **120***g* of the rigid flex circuit **106***c* proximate wire bond connection point **146***f*, which can be in communication with one or more interconnect layers within the rigid flex circuit **106***c* that convey signals. Molding material **404***a* can then be applied to encase the controller die **400***a*. Alternatively, the controller die **400***a* can be pre-molded with the molding material **404***a* before being attached to the rigid flex circuit **106***c*. One or more electrical connector can, in some cases, connect the controller die **400***a* to the wire bond connection point **146***f*. In other cases, the controller die **400***a* can interconnect with one or more interior signal conveying layers (e.g., interconnect layer(s)) in the stack of layers within the rigid flex circuit **106***c*, such as through vias (not shown). Accordingly, in some embodiments, the communication between the dies **110** of the die stack **102***i* and the controller die **400***a* can be accomplished through one or more layers of the rigid flex circuit **106***c*. This provides the advantage of freeing space within the substrate **142** that may previously have been used for signal routing between the die stack **102***i* and the controller die **400***a*.

[0060] FIG. **4**B shows the rigid flex circuit **106***c* bent to position the die stack **102***i* over the controller die **400***a* to form a generally vertically aligned assembly **140***c* in accordance with embodiments of the present technology. The rigid flex circuit **106***c* can be bent at flexible portion

122*e* to extend substantially vertically proximate the molding material **404***a*. The flexible portion **122***e* can have a length to accommodate the height of the molding material **404***a*. The rigid flex circuit **106***c* is bent to extend the rigid region **120***f* along a top surface of the molding material **404***a*. The rigid flex circuit **106***c* is again bent at flexible portion **122***d* to position the rigid region **120***e* over the rigid region **120***f*.

[0061] FIG. **4**C shows the vertically aligned assembly **140***c* of FIG. **4**B mounted to a substrate **142** with a stack **406** of other components in accordance with embodiments of the present technology. In some embodiments, the stack **406** may include a plurality of DRAM dies, while the die stack **102***i* includes NAND dies. The rigid flex circuit **106***c* conveys signals associated with the die stack **102***i* and the controller die **400***a* to/from the wire bond connection point **146***f*. Electrical connector **112***m* connects the wire bond connection point **146***f* on the rigid flex circuit **106***c* with wire bond connection point **146***g* on the substrate **142**.

[0062] FIG. **4**D illustrates a semiconductor device **100***d* wherein the controller die **400***b* is mounted on the opposite side of rigid flex circuit **106***d* than die stack **102***j* in accordance with embodiments of the present technology. For example, the die stack **102***j* is mounted to the first side **104***b* of the rigid flex circuit **106***d* and the controller die **400***b* is mounted to the second side **108***b* of the rigid flex circuit **106***d*. In this embodiment, the rigid flex circuit **106***b* can be shorter (compared to the rigid flex circuit **106***c* of FIG. **4**A) and configured with fewer alternating rigid regions **120** and flexible portions **122**. For example, the rigid flex circuit **106***d* can include two rigid regions **120***i-j* with one flexible portion **122***f* therebetween. The rigid flex circuit **106***d* can be bent in the direction of arrow **124***d* to vertically align the rigid regions **120***i-j* with each other, forming a vertically aligned assembly **140** similar to the vertically aligned assembly **140***c* of FIG. **4**C. The vertically aligned assembly **140** can be mounted on the substrate **142** as discussed in FIGS. **1**C and **4**C.

[0063] FIG. **5**A illustrates a semiconductor device **100***e* that has three die stacks **102***k-m* mounted on alternating sides of the rigid flex circuit **106***e* in accordance with embodiments of the present technology. The three die stacks **102***k-m* are mounted on rigid regions **120** that alternate with two flexible portions as previously discussed. Spacers **118***g-h* are attached to top sides **114***d-e* of the die stacks **102***k-l*, respectively. Spacer **118***i* is attached on the opposite side of the rigid flex circuit **106***e* as the die stack **102***m*. The electrical connectors **112** can be attached between the dies **110**, die stacks **102***k-m*, and the rigid flex circuit **106***e* as previously discussed in FIG. **1**A.

[0064] The rigid flex circuit **106***e* can be bent in the direction of arrow **124***e* to vertically align the die stacks **102***k-l*. When bent, the spacer **118***h* can be in mechanical connection with the rigid flex circuit **106***e*.

[0065] Die stack **102***n* can be mounted on substrate **142** and the electrical connectors **112** can be attached between the dies **110**, die stack **102***n*, and the substrate **142** as discussed in FIG. **3**. The semiconductor device **100***e* can be attached or mounted on the substrate **142** as previously discussed, positioning the spacer **118***i* in mechanical connection with top side **114***f* of the die stack **102***n* as shown in FIG. **5**B. When bent, the rigid flex circuit **106***e* forms vertically aligned assembly **140***d* and combines with the die stack **102***n* to form vertically aligned assembly **140***e*. The rigid flex circuit **106***e* can be electrically connected to the substrate **142** through electrical connector **112***n*.

[0066] A technical advantage of side-by-side embodiments is that the die stacks **102**, controller die (not shown) and/or other components, can be mounted to the rigid flex circuit **106**, and then attached to a die stack **102** (such as the die stack **102***n*) or other component that does not communicate through the rigid flex circuit **106***e*, as shown in FIG. **5**B. The signals to/from the die stacks **102***k-m* are conveyed through the rigid flex circuit **106***e* and through electrical connector **112***n* to the substrate **142**, providing the benefit of reducing the routing space previously needed on the substrate **142** for the signals associated with the die stacks **102***k-m*. Signals to/from the die stack **102***n* are conveyed through electrical connectors **112***o-p* to the substrate **142**, wherein each of the electrical connectors **112***o* and **112***p* conveys information for a plurality of die **110** in the die stack **102***n*. As with other embodiments herein, it should be understood that other numbers of die **110** can be used to form a die stack **102**, and different numbers of die stacks **102** can be vertically aligned and/or positioned in close proximity to each other. Also, the rigid flex circuit **106** can be configured to mechanically interface with different numbers of die stacks **102** and/or other components mounted to the substrate **142**, such as two side-by-side die stacks **102** or a die stack **102** positioned proximate a controller die **400**.

[0067] FIG. **5**C shows top and bottom views **130***b*, **132***b* of the rigid flex circuit **106***e* with the die stacks **102***k-m* and spacers **118***g-i* attached. The die stacks **102***k-m* can be mounted to the rigid flex circuit **106***e* as previously discussed. As shown, the spacers **118***g-i* are attached either to the surface of rigid region **120***k* of the rigid flex circuit **106***e* or the top side **114***d-e* of the die stacks **102***k-l* as shown in FIG. **5**A. It should be understood that spacers **118** can be mounted to any of the surfaces, including the substrate **142**, to provide the mechanical separation of applicable components.

[0068] FIGS. **6**A-C illustrate using a jig to assemble the semiconductor devices **100** in accordance with embodiments of the present technology. In some embodiments, strips of the laminated material can be formed individually before the components are attached to the rigid flex circuits **106**. A plurality of the individual strips of laminated material can be held in place by a piece of material.

[0069] FIG. **6**A shows a plurality of semiconductor devices **100** that can be held in place by a supportive material **600**. Individual dies **110**, die stacks **102**, spacers **118**, and/or other components such as controller dies **400** can be attached to the rigid flex circuits **106**. In some cases, the die stacks **102** are formed on the rigid flex circuits **106**, while in others, the die stacks **102** have been pre-formed separately and are then attached.

[0070] The die stack assemblies shown in FIG. **6**A correspond to the first side **104***a* of the semiconductor devices **100***a* of FIG. **1**A. The die stacks **102***a* and **102***c* are mounted on the rigid regions **120***a* and **120***c*, respectively, and the spacer **118***b* is mounted on the rigid region **120***b*. The flexible portions **122***a-c* alternate with the rigid regions **120***a-d*. In some cases, the dies **110** on the bottom half of the die stacks **102***a* and **102***c* can be mounted, such as with a die attach tool. A wire bond tool can then attach the electrical connectors **112** to the mounted dies **110**. This process can be repeated to mount the top half of the die stacks **102***a* and **102***c* and attach the electrical connectors **112**. In other embodiments, the electrical connectors can be attached after all of the components are attached to a first side of the rigid flex circuit **106**. Therefore, the die stacks **102***a* and **102***c* can undergo parallel die attach and wire bonding steps, providing an advantage of minimizing the number of iterations required for assembling the die stacks **102** on the rigid flex circuit **106**.

[0071] After the components and desired mechanical and electrical connections are complete, a jig **602**, as shown in FIG. **6**B, can be applied to the material **600**. FIG. **6**C shows the assembly of FIG. **6**A that has been rotated or flipped such that the components (e.g., the die stacks **102***b* and **102***d* and the spacers **118***a* and **118***c*) can be mounted as discussed above to the second side **108** of the semiconductor devices **100***a*, along with the interconnecting electrical connectors **112**. Once all of the components are in place and electrical/mechanical connections are complete, the semiconductor devices **100** can be separated or singulated from the material **600**. It should be understood that other assembly processes are contemplated, including assembling the semiconductor devices **100** individually, by hand, by a machine, in large separable sheets, etc., and that the embodiments are not limited to the assembly/fabrication process shown in FIGS. **6**A-**6**C.

[0072] FIG. **7** is a flow chart illustrating a method of making a semiconductor device. The method includes mounting a first die to a first side of a first rigid region of a rigid flex circuit (box **710**). The method further includes mounting a second die to a second side of a second rigid region of the rigid flex circuit that is opposite to the first side of the first rigid region (box **720**). A flexible portion of the rigid flex circuit is flexed through about 180 degrees to bring the first and second rigid regions into generally vertical alignment with each other (box **730**).

[0073] Any one of the semiconductor devices, assemblies, and/or packages described above with reference to FIGS. **1**A through **7** can be incorporated into any of a myriad of larger and/or more

complex systems, a representative example of which is system **800** shown schematically in FIG. **8**. The system **800** can include a semiconductor device assembly **810**, a power source **820**, a driver **830**, a processor **840**, and/or other subsystems or components **850**. The semiconductor device assembly **810** can include features generally similar to those of the semiconductor device assemblies described above. The resulting system **800** can perform any of a wide variety of functions such as memory storage, data processing, and/or other suitable functions. Accordingly, representative systems **800** can include, without limitation, hand-held devices (e.g., mobile phones, tablets, digital readers, and digital audio players), computers, vehicle and other machines and appliances. Components of the system **800** may be housed in a single unit or distributed over multiple, interconnected units (e.g., through a communications network). The components of the system **800** can also include remote devices and any of a wide variety of computer readable media.
[0074] From the foregoing, it will be appreciated that specific embodiments of the technology have been described herein for purposes of illustration, but that various modifications may be made without deviating from the disclosure. Accordingly, the technology is not limited except as by the appended claims. Furthermore, certain aspects of the new technology described in the context of particular embodiments may also be combined or eliminated in other embodiments. Moreover, although advantages associated with certain embodiments of the new technology have been described in the context of those embodiments, other embodiments may also exhibit such advantages and not all embodiments need necessarily exhibit such advantages to fall within the scope of the technology. Accordingly, the disclosure and associated technology can encompass other embodiments not expressly shown or described herein.

Claims

1. A semiconductor device, comprising: a rigid flex circuit having a first rigid region and a second rigid region electrically connected by a flexible portion; a first die mounted to a first surface of the first rigid region; and a second die mounted to a second surface of the second rigid region, the first and second surfaces being on opposite sides of the rigid flex circuit, wherein the flexible portion is bent to hold the first and second rigid regions in generally vertical alignment with each other.
2. The semiconductor device of claim 1, wherein the first rigid region further comprises at least one bond pad on the first surface.
3. The semiconductor device of claim 1, further comprising a first electrical connector electrically coupling the first die and the rigid flex circuit within the first rigid region.
4. The semiconductor device of claim 1, further comprising: a package substrate coupled to a third surface of the second rigid region opposite the second surface; and a second electrical connector electrically coupling the package substrate and the rigid flex circuit within the second rigid region.
5. The semiconductor device of claim 1, further comprising a third die mounted over at least a portion of an exposed side of the first die.
6. The semiconductor device of claim 5, further comprising at least one electrical connector connecting the first die and the third die.
7. A semiconductor device, comprising: a rigid flex circuit having a first rigid region and a second rigid region electrically connected by a flexible portion, each of the first and second rigid regions having at least one bond pad thereon, wherein the flexible portion is configured to be flexed through about 180 degrees to hold the first and second rigid regions in generally vertical alignment with each other; a first die mounted to a first surface of the first rigid region, the first die electrically connected to the at least one bond pad on the first rigid region; a second die mounted to a second surface of the second rigid region, the second die electrically connected to the at least one bond pad on the second rigid region, wherein the first surface of the first rigid region and the second surface of the second rigid region are on opposite sides of the rigid flex circuit; a package substrate connected to the rigid flex circuit; and an electrical connector connecting the rigid flex

circuit and the substrate.
8. The semiconductor device of claim 7, wherein the rigid flex circuit further comprises a third rigid region and a second flexible portion, wherein the second flexible portion is flexed through about 180 degrees to hold the first, second, and third rigid regions generally in vertical alignment with each other.
9. The semiconductor device of claim 7, wherein the rigid flex circuit includes an interconnect layer extending along at least a portion of a length of the rigid flex circuit, at least a portion of the interconnect layer electrically connected to at least one of the bond pads.
10. The semiconductor device of claim 7, further comprising at least a third die mounted over at least a portion of the first die to form a die stack.
11. The semiconductor device of claim 7, further comprising: a third die stack mounted to the substrate, the third die stack comprising at least one die; and at least one second electrical connector coupling at least some of the dies in the third die stack and the substrate, the third die stack positioned between the substrate and at least a portion of the rigid flex circuit.
12. The semiconductor device of claim 7, further comprising: a first plurality of dies mounted over the first die to form a first die stack, the first die and the first plurality of dies being electrically connected to each other; and a second plurality of dies mounted over the second die to form a second die stack, the second die and the second plurality of dies being electrically connected to each other.
13. The semiconductor device of claim 7, wherein the first and second dies are each one of a semiconductor die, a controller die, a molded controller die, or a memory die.
14. A method for forming a semiconductor device, comprising: mounting a first die to a first surface of a first rigid region of a rigid flex circuit; mounting a second die to a second surface of a second rigid region of the rigid flex circuit, the first surface and the second surface being on opposite sides of the rigid flex circuit; and flexing a flexible portion through about 180 degrees to bring the first and second rigid regions into generally vertical alignment with each other, the flexible portion extending between and electrically connecting the first and second rigid regions.
15. The method of claim 14, further comprising electrically connecting the first and second dies to the first and second rigid regions, respectively.
16. The method of claim 14, further comprising mounting a plurality of dies over at least a portion of the first die to form a die stack.
17. The method of claim 16, further comprising electrically connecting the plurality of dies and the first die together.