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Laser ablation-based surface property modification and contamination removal

Abstract

Embodiments disclosed herein include electronic packages. In an embodiment, the electronic package comprises a mold layer and a die embedded in the mold layer. In an embodiment the electronic package further comprises a solder resist with a first surface over the mold layer and a second surface opposite from the first surface. In an embodiment, the second surface comprises a first cavity into the solder resist.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a continuation of U.S. patent application Ser. No. 16/557,771, filed on Aug. 30, 2019, the entire contents of which is hereby incorporated by reference herein.

TECHNICAL FIELD

(1) Embodiments of the present disclosure relate to semiconductor devices, and more particularly to surface property modification of solder resist layers to improve package performance.

BACKGROUND

(2) Thermal performance is a critical concern in many advanced packaging architectures. In particular, package-on-package (PoP) architectures require careful consideration of thermal performance since the underlying package (e.g., a system-on-chip (SoC) package) is entirely covered by the top package (e.g., a memory package). Accordingly, the path for thermal dissipation from the SoC is up through the memory package. In order to reduce the thermal resistance, an air gap between the two packages may be filled by a thermal adhesive layer.

(3) It has been found that the thermal adhesive layer has poor adhesion to the top package. Particularly, surface contaminants on a solder resist layer significantly reduce the surface energy of the solder resist. This provides poor wetting, and ultimately leads to significant assembly issues including delamination and voiding. The surface contaminants (e.g., PDMS) are typically the result of upstream assembly of the top package, and it has proven difficult to eliminate the contaminants. Accordingly, solutions to remove the contaminants have been suggested. For example, solvent-based wet etching and fluorinated plasma etching approaches have been proposed to remove contaminants from the solder resist surface. However, both etching processes are global in nature and leave etchant residues which required further cleaning and/or showed other undesirable effects such as solder resist and buildup film swelling.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. 1A is a cross-sectional illustration of a top package of a package-on-package (PoP) architecture with a solder resist layer that includes a cavity, in accordance with an embodiment.

(2) FIG. 1B is a cross-sectional illustration of a top package of a PoP architecture with a solder resist layer that includes a first cavity and a plurality of second cavities, in accordance with an embodiment.

(3) FIG. 1C is a cross-sectional illustration of a top package of a PoP architecture with a solder resist layer that includes a deep first cavity, in accordance with an embodiment.

(4) FIG. 2A is a perspective view illustration of an electronic package that illustrates a solder resist layer with a cavity, in accordance with an embodiment.

(5) FIG. 2B is a perspective view illustration of an electronic package that illustrates a solder resist layer with a first cavity and a plurality of second cavities within the first cavity, in accordance with an embodiment.

(6) FIG. 3A is a zoomed in plan view illustration of an electronic package that illustrates an edge of a cavity into a solder resist layer, in accordance with an embodiment.

(7) FIG. 3B is a cross-sectional illustration of a solder resist layer that illustrates the surface roughness differences of a solder resist within a cavity and outside the cavity, in accordance with an embodiment.

(8) FIG. 4A is a cross-sectional illustration of an electronic system that includes a PoP architecture with a thermal adhesive between a top package and a bottom package, where the solder resist layer of the top package has a cavity, in accordance with an embodiment.

(9) FIG. 4B is a cross-sectional illustration of an electronic system that includes a PoP architecture

with a thermal adhesive between a top package and a bottom package, where the solder resist layer of the top package has a first cavity and a plurality of second cavities within the first cavity, in accordance with an embodiment.

(10) FIG. 4C is a cross-sectional illustration of an electronic system that includes a PoP architecture with a thermal adhesive between a top package and a bottom package, where the solder resist layer of the top package has a cavity that extends nearly all the way through the solder resist layer, in accordance with an embodiment.

(11) FIG. 5 is a schematic of a computing device built in accordance with an embodiment.

EMBODIMENTS OF THE PRESENT DISCLOSURE

(12) Described herein are electronic packages with surface property modification of solder resist layers to improve package performance, in accordance with various embodiments. In the following description, various aspects of the illustrative implementations will be described using terms commonly employed by those skilled in the art to convey the substance of their work to others skilled in the art. However, it will be apparent to those skilled in the art that the present invention may be practiced with only some of the described aspects. For purposes of explanation, specific numbers, materials and configurations are set forth in order to provide a thorough understanding of the illustrative implementations. However, it will be apparent to one skilled in the art that the present invention may be practiced without the specific details. In other instances, well-known features are omitted or simplified in order not to obscure the illustrative implementations.

(13) Various operations will be described as multiple discrete operations, in turn, in a manner that is most helpful in understanding the present invention, however, the order of description should not be construed to imply that these operations are necessarily order dependent. In particular, these operations need not be performed in the order of presentation.

(14) As noted above, thermal adhesive material between a bottom package and a top package in package-on-package (PoP) architectures has exhibited poor adhesion. Particularly, surface contaminants (e.g., PDMS) on the solder resist of the top package reduce the surface energy and result in manufacturing issues such as delamination and voiding. Accordingly, embodiments disclosed herein include treatments to the top package that eliminate the presence of contaminants on the solder resist.

(15) In an embodiment, the contaminants are removed with a laser ablation process. The use of laser ablation provides advantages over the etching processes described above. For example, a laser ablation process may be a localized process. That is, laser ablation may be implemented at locations where the thermal adhesive will be present instead of across the entire solder resist layer, as is the case with the etching processes disclosed above. In an embodiment, the laser ablation process also does not produce residues that require further cleaning.

(16) Another advantage of embodiments disclosed herein is that the laser ablation process may be used to reduce the thickness of the solder resist layer. This is particularly beneficial because the solder resist layer typically has a high thermal resistance. Furthermore, simply reducing the thickness of the solder resist during application of the solder resist is not possible due to manufacturing concerns. For example, solder resist layers are generally approximately 20 μm or greater. Accordingly, the solder resist layer serves as a thermal barrier. By reducing the thickness of the solder resist layer with a laser ablation process, the thermal performance of the package is improved. Additionally, selectively ablating the solder resist layer allows for hot spot locations to be mitigated through additional solder resist removal.

(17) In some embodiments, the laser ablation may include the formation of a first cavity that extends into the solder resist layer. The first cavity may have a depth that is sufficient to remove the contaminants on the surface. For example, the first cavity may have a depth that is approximately 5 μm or less. In other embodiments, the first cavity may extend substantially through the thickness of the solder resist layer. For example, the first cavity may have a depth that is between approximately 10 μm and 20 μm . Deeper cavities such as these may allow for improved thermal performance, as

described above. In yet another embodiment, a first cavity may be formed and one or more second cavities within the first cavity may be formed. The first cavity may be used to remove the surface contaminants, and the second cavities may be positioned over hot spots of the electronic package in order to improve thermal performance.

(18) Referring now to FIGS. **1A-1C**, cross-sectional illustrations of various electronic packages **120** are shown, in accordance with an embodiment. In an embodiment, the electronic packages **120** in the FIGS. **1A-1C** may be substantially similar to each other, with the exception that the solder resist layer **125** have different architectures.

(19) Referring now to FIG. **1A**, a cross-sectional illustration of an electronic package **120** is shown, in accordance with an embodiment. In a particular embodiment, the electronic package **120** is a top package of a PoP architecture. That is, the electronic package **120** may be configured to be disposed over an underlying package (not shown). In an embodiment, the electronic package **120** may comprise one or more dies **122**. For example, a first die **122.sub.A** and a second die **122.sub.B** are shown as being stacked over each other. In some embodiments, a die attach film (DAF) **123** may be used to secure the first die **122.sub.A** to the second die **122.sub.B**. The stacked dies **122** may be stacked offset from each other to allow for wire bonds **124** to be made down to conductive pads (now shown) on the solder resist layer **125**. In an embodiment, the stacked dies **122** may be disposed over a package substrate **129** (e.g., organic build-up layers or the like). In an embodiment, the stacked dies **122** may be embedded in a mold layer **121**.

(20) In an embodiment, a solder resist layer **125** may be disposed over a surface of the package substrate **129**. For example, a first surface **126** of the solder resist layer **125** may be in contact with the package substrate **129**. In an embodiment, the solder resist layer **125** may have a thickness **T**. For example, the thickness **T** may be approximately 15 μm or greater, or approximately 20 μm or greater. In an embodiment, the solder resist layer **125** may also have a second surface **127** that is opposite from the first surface **126**. The second surface **127** may include surface contaminants (not visible in FIG. **1A**). For example, the surface contaminants may include PDMS or the like. The presence of surface contaminants results in a reduction in surface energy. This provides poor wetting of a thermal adhesive and can ultimately cause manufacturing defects such as delamination and/or voiding. The surface contaminants may be the result of upstream processing during assembly and/or handling of the electronic package **120**.

(21) As noted above, the removal of the surface contaminants from the second surface **127** of the electronic package **120** is critical to providing a high yield assembly process. Accordingly, embodiments include the formation of a cavity **130** into the second surface **127**. In an embodiment, the cavity **130** may have a first depth **D.sub.1** (measured from the second surface **127** to a bottom of the cavity **130**) that is sufficient to remove the surface contaminants. That is the first depth **D.sub.1** may only remove a small portion of the solder resist layer **125** proximate to the second surface **127**. For example, the first depth **D.sub.1** may be approximately 10% of the thickness **T** or less, or approximately 5% of the thickness **T** or less. In a particular embodiment, the first depth **D.sub.1** may be approximately 5 μm or less, or approximately 3 μm or less.

(22) In an embodiment, the cavity **130** does not occupy the entire second surface **127** of the solder resist layer **125**. That is, the second surface **127** is not entirely removed. Accordingly, in some embodiments, there may be portions of the solder resist layer **125** that still include surface contaminants. For example, the remaining portions of the second surface **127** may still have surface contaminants, and the exposed portions of the solder resist layer **125** within the cavity **130** may be free from the surface contaminants.

(23) In an embodiment, the cavity **130** has a shape and size that provides a desired area suitable for adhesion to an underlying package (not shown). That is, the cavity **130** has dimensions that are suitable for providing sufficient surface area onto which a thermal adhesive may be dispensed. In the illustrated embodiment, the cavity **130** has a width that is less than the width of the overlying dies **122**. However, it is to be appreciated that the cavity **130** may also have a width that is greater

than a width of the overlying dies **122** in some embodiments. Furthermore, while the cavity **130** is shown as being entirely within a footprint of the first die **122.sub.A**, it is to be appreciated that the cavity **130** may also extend beyond a footprint of the first die **122.sub.A**. Furthermore, while a single cavity **130** is shown, it is to be appreciated that any number of cavities **130** may be arranged across the second surface **127** of the solder resist layer **125**.

(24) Referring now to FIG. **1B**, a cross-sectional illustration of an electronic package **120** is shown, in accordance with an additional embodiment. In an embodiment, the electronic package **120** in FIG. **1B** is substantially similar to the electronic package **120** in FIG. **1A**, with the exception that a plurality of second cavities **132** are disposed within the first cavity **130**. In an embodiment, the second cavities **132** may have a second depth $D_{sub.2}$ (measured from the second surface **127** to the bottom of the second cavity **132**) that is greater than the first depth $D_{sub.1}$. In an embodiment, the second depth $D_{sub.2}$ may be approximately 75% of the thickness T or more, or approximately 95% of the thickness T or more. In a particular embodiment, the second depth $D_{sub.2}$ may be chosen so that only approximate 5 μm or less, or approximately 1 μm or less of the solder resist layer **125** remains between the bottom of the second cavity **132** and the first surface **126**.

(25) In an embodiment, the second depth $D_{sub.2}$ is less than the thickness T . This ensures that the second cavity **132** does not pass all the way through the solder resist layer **125**. Keeping the second cavity **132** from passing all the way through the solder resist layer **125** is important because the bottom surface of the package substrate **129** cannot be exposed. That is, copper or other materials of the package substrate **129** over the first surface **126** remain covered by at least a portion of the solder resist layer **125**.

(26) In an embodiment, the inclusion of one or more second cavities **132** provides improved thermal performance to the electronic package **120**. Since the solder resist layer **125** has a high thermal resistance (e.g., in some embodiments, the solder resist layer **125** has the highest thermal resistance of the electronic package **120**), removing significant portions of the solder resist layer **125** reduces the thermal resistance of the electronic package **120**. Accordingly, thermal energy from an underlying package (not shown) may more easily propagate up through the electronic package **120**.

(27) In the illustrated embodiment, two second cavities **132** are shown. However, it is to be appreciated that there may be any number of second cavities **132** (e.g., one or more). In an embodiment, the second cavities **132** are substantially centered within the first cavity **130**. However, it is to be appreciated that the second cavities **132** may be located anywhere within the first cavity **130**. For example, the second cavities **132** may be located in locations where hot spots are expected. This allows for improved thermal performance, since second cavities **132** allow for improved heat removal from the hot spots. In other embodiments, the second cavities **132** may also be outside of the first cavity **130**.

(28) Referring now to FIG. **1C**, a cross-sectional illustration of an electronic package **120** is shown, in accordance with an embodiment. In an embodiment, the electronic package **120** in FIG. **1C** may be substantially similar to the electronic package **120** in FIG. **1A**, with the exception that the cavities **130** includes a second depth $D_{sub.2}$ that is greater than the first depth $D_{sub.1}$ in FIG. **1A**. In an embodiment, the second depth $D_{sub.2}$ may be approximately 75% of the thickness T or more, or approximately 95% of the thickness T or more. In a particular embodiment, the second depth $D_{sub.2}$ may be chosen so that only approximate 5 μm or less, or approximately 1 μm or less of the solder resist layer **125** remains between the bottom of the cavity **130** and the first surface **126**.

(29) In an embodiment, the second depth $D_{sub.2}$ is less than the thickness T . This ensures that the cavity **130** does not pass all the way through the solder resist layer **125**. Keeping the cavity **130** from passing all the way through the solder resist layer **125** is important because the bottom surface of the package substrate **129** cannot be exposed. That is, copper or other materials of the package substrate over the first surface **126** remain covered by at least a portion of the solder resist layer

125.

(30) Referring now to FIG. 2A, a perspective view illustration of an electronic package 220 is shown, in accordance with an embodiment. In the illustrated embodiment, the one or more dies are hidden from view by the mold layer 221. As shown, a solder resist layer 225 is over a surface of the package substrate 229 that is disposed over the surface of the mold layer 221. A cavity 230 may be formed into the solder resist layer 225. The cavity 230 may have a bottom surface 234 and sidewall surfaces 236. In the illustrated embodiment, the sidewall surfaces 236 are shown as being substantially vertical. However, it is to be appreciated that the sidewall surfaces 236 may have a tapered profile, as will be described in greater detail below.

(31) In an embodiment, the cavity 230 extends a first depth D.sub.1 into the surface 227 of the solder resist layer 225. That is, a bottom surface 234 of the cavity 230 may be spaced away (in the Z-direction) from the exposed surface 227 of the solder resist layer 225 by the first depth D.sub.1. In an embodiment, the first depth D.sub.1 may be similar to the first depth D.sub.1 in FIG. 1A. For example, the first depth D.sub.1 may be approximately 10% of the thickness of the solder resist layer 225 or less, or approximately 5% of the thickness of the solder resist layer 225 or less. In a particular embodiment, the first depth D.sub.1 may be approximately 5 μm or less, or approximately 3 μm or less. In other embodiments, the first depth D.sub.1 may be similar to the second depth D.sub.2 in FIG. 1C. For example, the first depth D.sub.1 may be approximately 75% of the thickness of the solder resist layer 225 or more, or approximately 95% of the thickness of the solder resist layer 225 or more. In a particular embodiment, the first depth D.sub.1 may be chosen so that only approximate 5 μm or less, or approximately 1 μm or less of the solder resist layer 225 remains between the bottom of the cavity 230 and the surface of the mold layer 221.

(32) Referring now to FIG. 2B, a perspective view illustration of an electronic package 220 with a first cavity 230 and a plurality of second cavities 232 is shown, in accordance with an embodiment. In an embodiment, the electronic package 220 may be substantially similar to the electronic package 220 in FIG. 2A, with the exception that the second cavities 232 are formed into the bottom surface 234 of the first cavity 230. For example, a set of four second cavities 232 are arranged across the bottom surface 234 of the first cavity 230. However, it is to be appreciated that any number of second cavities 232 may be disposed into the bottom surface 234 of the first cavity 230. In an embodiment, the second cavities 232 may include a bottom surface 244 and sidewall surfaces 246. The sidewall surfaces 246 are illustrated as being substantially vertical, but it is to be appreciated that in other embodiments the sidewall surfaces 246 may be tapered.

(33) In an embodiment, the first cavity 230 may have a first depth D.sub.1 and the second cavities 232 may have a second depth D.sub.2. The first depth D.sub.1 may be measured from the bottom surface 234 to the surface 227, and the second depth D.sub.2 may be measured from the bottom surface 244 to the surface 227. In an embodiment, the first depth D.sub.1 may be similar to the first depth D.sub.1 in FIG. 1B. For example, the first depth D.sub.1 may be approximately 10% of the thickness of the solder resist layer 225 or less, or approximately 5% of the thickness of the solder resist layer 225 or less. In a particular embodiment, the first depth D.sub.1 may be approximately 5 μm or less, or approximately 3 μm or less. In an embodiment, the second depth D.sub.2 may be similar to the second depth D.sub.2 in FIG. 1B. For example, the second depth D.sub.2 may be approximately 75% of the thickness of the solder resist layer 225 or more, or approximately 95% of the thickness of the solder resist layer 225 or more. In a particular embodiment, the second depth D.sub.2 may be chosen so that only approximate 5 μm or less, or approximately 1 μm or less of the solder resist layer 225 remains between the bottom of the cavity 230 and the surface of the mold layer 221.

(34) In FIGS. 2A and 2B, the bottom surfaces 234, 244 of the cavities 230, 232 are shown as being smooth and the sidewall surfaces 236, 246 are shown as being substantially vertical. However, it is to be appreciated that electronic packages may include sidewalls and surfaces that are not perfectly flat, vertical, etc. Additionally, while the perimeters of the cavities 230, 232 are shown as being rectangular with linear edges, embodiments are not limited to such configurations.

(35) For example FIGS. 3A and 3B illustrate zoomed in illustrations of the topography of the solder resist layer **325** on an electronic package in accordance with an embodiment.

(36) Referring now to FIG. 3A, a plan view illustration of a portion of the solder resist layer **325** is shown, in accordance with an embodiment. The portion of the solder resist layer **325** depicts a surface **327** of the solder resist layer **325** and a bottom surface **334** of a portion of a cavity **330**. As shown, the cavity **330** does not have a linear edge. Particularly, the cavity **330** may have a jagged edge. In some embodiments the edge of the cavity **330** may be referred to as a scalloped edge.

(37) The shape of the perimeter of the cavity **330** is the result of the processing used to form the cavity **330**. Particularly, when the cavity **330** is formed by a laser ablation process, the laser beam may not provide a perfectly linear edge depending on the settings of the laser. For example, in order to increase the throughput, the speed and spot size of the laser may be increased. This may result in the scalloping of the perimeter of the cavity, similar to what is shown in FIG. 3A.

However, it is to be appreciated that laser ablation processing may also be able to provide substantially linear edges without scalloping, and such embodiments are also included herein.

(38) Referring now to FIG. 3B, a cross-sectional illustration of the solder resist layer **325** is shown, in accordance with an embodiment. As shown, the surface **327** of the solder resist layer **325** may have a first surface roughness and the bottom surface **334** of the cavity **330** may have a second surface roughness. For example, the second surface roughness of the bottom surface of the cavity **330** is greater than the first surface roughness of the surface **327**. The increased surface roughness may be attributable to the laser ablation used to form the cavity **330**.

(39) The increased surface roughness of the bottom surface **334** of the cavity **330** may provide improved adhesion. That is, the increased surface roughness provides more surface area to which the thermal adhesive may bond. Accordingly, voiding and delamination is further reduced. In some embodiments, the difference in the surface roughness between the bottom surface **334** of the cavity **330** and the surface **327** may also result in optical differences to the solder resist layer **325**. For example, the bottom surface **334** of the cavity **330** may be optically darker than the surface **327** due to the surface roughness of the bottom surface **334** diffracting more light.

(40) Due to the bottom surface **334** having a relatively high surface roughness, it is to be appreciated that the depth **D** of the cavity may not be uniform at all locations across the cavity **330**. Accordingly, it is to be appreciated that the depths **D** (e.g., **D.sub.1**, **D.sub.2**, etc.) referred to herein may represent an average depth of the various cavities.

(41) FIG. 3B also illustrates that the sidewall surface **336** need not be perfectly vertical. For example, the sidewall surface **336** may have a substantially tapered profile. In an embodiment, a surface roughness of the sidewall surface **336** may be greater than the surface roughness of the surface **327**. In some embodiments, the surface roughness of the sidewall surface **336** may be similar to the surface roughness of the bottom surface **334**.

(42) Referring now to FIGS. 4A-4C, cross-sectional illustrations of electronic systems **460** are shown, in accordance with various embodiments. In an embodiment, the electronic systems **460** in FIGS. 4A-4C are substantially similar to each other with the exception of having different cavity configurations in the solder resist layer **425** of the second (top) package **420**.

(43) Referring now to FIG. 4A, a cross-sectional illustration of an electronic system **460** is shown, in accordance with an embodiment. In an embodiment, the electronic system **460** includes a board **461**. The board **461** may be a printed circuit board (PCB) or the like. In an embodiment a first package **480** may be electrically coupled to the board **461** by interconnects **462**. The interconnects **462** are shown as solder bumps, but it is to be appreciated that any interconnect architecture may be used to connect the first package **480** to the board **461**.

(44) In an embodiment, the first package **480** may comprise a package substrate **463**. The package substrate **463** may comprise conductive traces, vias, pads, etc. (not shown) that are embedded in one or more dielectric layers. In some embodiments the package substrate **463** may comprise a core or the package substrate **463** may be coreless. In an embodiment, one or more dies may be

electrically coupled to the package substrate **463**. For example a first die **466** is directly attached to the package substrate **463**. One or more second dies **467** may be coupled to the first die **466**. In an embodiment, the first die **466** may include transistors fabricated at a first process node and the second dies **467** may include transistors fabricated at a second process node that is more advanced than the first process node. In an embodiment, the first package **480** may also comprise one or more mold layers **464**. The mold layers **464** may embed the dies **467**, **466**. In some embodiments, through mold interconnects (TMIs) **465** may pass through the mold layer **464**. In an embodiment, the first package **480** may be a system on a chip (SoC), or any other multi-chip package architecture.

(45) In an embodiment, the electronic system **460** may further comprise a second package **420**. The second package **420** may be electrically coupled to the first package **480** by the TMIs **465**. For example, wire bonds **424** may provide electrical coupling between dies **422.sub.A** and **422.sub.B** and the TMIs **465**. Accordingly, the dies **422** of the second package **420** may be electrically coupled to the dies **466**, **467** of the first package **480**. In an embodiment, the dies **422** may be memory dies. In an embodiment, the dies **422** may be embedded in a mold layer **421**.

(46) In an embodiment, a solder resist layer **425** may be disposed over a package substrate **429**, and the package substrate **429** may be in contact with the mold layer **421** of the second package **420**. For example, a first surface **426** of the solder resist layer **425** may contact the package substrate **429**, and a second surface **427** of the solder resist layer **425** may face towards the first package **480**. In an embodiment, a cavity **430** may be disposed into the second surface **427** of the solder resist layer **425**. In an embodiment, a footprint of the cavity **430** may cover a footprint of the die **466**. The cavity **430** may be substantially similar to the cavity **130** described above with respect to FIG. 1A.

(47) In an embodiment, a thermal adhesive **468** may fill the space between the first package **480** and the second package **420**. In an embodiment, the thermal adhesive may be a thermally conductive epoxy, polymer, or the like. The thermal adhesive **468** may substantially fill the cavity **430** of the solder resist layer **425**. Particularly, it is noted that the formation of the cavity **430** removes surface contaminants from the portions of the solder resist layer **425** that interfaces with the thermal adhesive **468**. As such, the surface energy is increased and the adhesion is improved. This results in a decrease in delamination and voiding. The formation of the cavity **430** may also locally increase the surface roughness of the solder resist layer **425** to further enhance the adhesion.

(48) Referring now to FIG. 4B, a cross-sectional illustration of an electronic system **460** is shown, in accordance with an additional embodiment. In an embodiment, the electronic system **460** is substantially similar to the electronic system **460** in FIG. 4A, with the exception that a plurality of second cavities **432** are disposed in the solder resist layer **425** within the first cavity **430**. As noted above the inclusion of second cavities **432** results in localized decreases in the thickness of the solder resist layer **425**. Accordingly, the thermal performance may be improved.

(49) In some embodiments, the second cavities **432** may be located over the dies **467**. That is, the footprint of each of the second cavities **432** covers a footprint of one of the dies **467**. Accordingly, the extra heat produced by the stacked dies **467** may be more easily dissipated. In some embodiments, the second cavities **432** do not entirely cover the footprint of one of the dies **467**. In such embodiments, the second cavities **432** may be positioned above hot-spots within the die **467**. Hot-spots may refer to portions of the die that run at higher temperatures in some or all use conditions. For example, hot-spots may refer to locations of the die **467** with a higher density of transistor devices than other regions of the die **467**. In an embodiment, the first cavity **430** and the second cavities **432** may be substantially similar to the first cavity **130** and the second cavities **132** in FIG. 1B.

(50) Referring now to FIG. 4C, a cross-sectional illustration of an electronic system **460** is shown, in accordance with an additional embodiment. The electronic system **460** may be substantially similar to the electronic system **460** in FIG. 4A, with the exception that the cavity **430** is deeper. For example, the cavity **430** may have a depth that substantially passes through a thickness of the

solder resist layer **425** without passing all the way through the solder resist layer **425**. Removing additional solder resist material improves the thermal performance of the electronic system **460**. In an embodiment, the cavity **430** may be substantially similar to the cavity **130** in FIG. 1C.

(51) FIG. 5 illustrates a computing device **500** in accordance with one implementation of the invention. The computing device **500** houses a board **502**. The board **502** may include a number of components, including but not limited to a processor **504** and at least one communication chip **506**. The processor **504** is physically and electrically coupled to the board **502**. In some implementations the at least one communication chip **506** is also physically and electrically coupled to the board **502**. In further implementations, the communication chip **506** is part of the processor **504**.

(52) These other components include, but are not limited to, volatile memory (e.g., DRAM), non-volatile memory (e.g., ROM), flash memory, a graphics processor, a digital signal processor, a crypto processor, a chipset, an antenna, a display, a touchscreen display, a touchscreen controller, a battery, an audio codec, a video codec, a power amplifier, a global positioning system (GPS) device, a compass, an accelerometer, a gyroscope, a speaker, a camera, and a mass storage device (such as hard disk drive, compact disk (CD), digital versatile disk (DVD), and so forth).

(53) The communication chip **506** enables wireless communications for the transfer of data to and from the computing device **500**. The term “wireless” and its derivatives may be used to describe circuits, devices, systems, methods, techniques, communications channels, etc., that may communicate data through the use of modulated electromagnetic radiation through a non-solid medium. The term does not imply that the associated devices do not contain any wires, although in some embodiments they might not. The communication chip **506** may implement any of a number of wireless standards or protocols, including but not limited to Wi-Fi (IEEE 802.11 family), WiMAX (IEEE 802.16 family), IEEE 802.20, long term evolution (LTE), Ev-DO, HSPA+, HSDPA+, HSUPA+, EDGE, GSM, GPRS, CDMA, TDMA, DECT, Bluetooth, derivatives thereof, as well as any other wireless protocols that are designated as 3G, 4G, 5G, and beyond. The computing device **500** may include a plurality of communication chips **506**. For instance, a first communication chip **506** may be dedicated to shorter range wireless communications such as Wi-Fi and Bluetooth and a second communication chip **506** may be dedicated to longer range wireless communications such as GPS, EDGE, GPRS, CDMA, WiMAX, LTE, Ev-DO, and others.

(54) The processor **504** of the computing device **500** includes an integrated circuit die packaged within the processor **504**. In some implementations of the invention, the integrated circuit die of the processor **504** may be part of an electronic package that comprises a thermal adhesive layer that fills a cavity in a solder resist layer, in accordance with embodiments described herein. The term “processor” may refer to any device or portion of a device that processes electronic data from registers and/or memory to transform that electronic data into other electronic data that may be stored in registers and/or memory.

(55) The communication chip **506** also includes an integrated circuit die packaged within the communication chip **506**. In accordance with another implementation of the invention, the integrated circuit die of the communication chip **506** may be part of an electronic package that comprises a thermal adhesive layer that fills a cavity in a solder resist layer, in accordance with embodiments described herein.

(56) The above description of illustrated implementations of the invention, including what is described in the Abstract, is not intended to be exhaustive or to limit the invention to the precise forms disclosed. While specific implementations of, and examples for, the invention are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize.

(57) These modifications may be made to the invention in light of the above detailed description. The terms used in the following claims should not be construed to limit the invention to the specific implementations disclosed in the specification and the claims. Rather, the scope of the invention is to be determined entirely by the following claims, which are to be construed in accordance with

established doctrines of claim interpretation.

(58) Example 1: an electronic package, comprising: a mold layer; a die embedded in the mold layer; and a solder resist with a first surface over the mold layer and a second surface opposite from the first surface, and wherein the second surface comprises a first cavity into the solder resist.

(59) Example 2: the electronic package of Example 1, wherein a depth of the first cavity is less than a thickness of the solder resist.

(60) Example 3: the electronic package of Example 1 or Example 2, wherein a bottom surface the first cavity has a first surface roughness and the second surface has a second surface roughness, and wherein the first surface roughness is greater than the second surface roughness.

(61) Example 4: the electronic package of Examples 1-3, wherein a perimeter of the first cavity is a scalloped edge.

(62) Example 5: the electronic package of Examples 1-4, further comprising a second cavity within the first cavity.

(63) Example 6: the electronic package of Example 5, wherein the first cavity has a first depth and the second cavity has a second depth, and wherein the second depth is greater than the first depth.

(64) Example 7: the electronic package of Example 5, further comprising a third cavity within the first cavity.

(65) Example 8: the electronic package of Examples 1-7, wherein the second surface comprises a contaminant, and a third surface the solder resist within the first cavity is free of the contaminant.

(66) Example 9: the electronic package of Example 8, wherein the contaminant is PDMS.

(67) Example 10: the electronic package of Examples 1-9, wherein the die is a memory die.

(68) Example 11: the electronic package of Example 10, further comprising: a plurality of memory dies over the first surface of the solder resist.

(69) Example 12: the electronic package of Examples 1-11, wherein a sidewall surface of the first cavity is tapered.

(70) Example 13: an electronic package, comprising: a first package, wherein the first package comprises: a package substrate; a first die over the package substrate; a second die over the first die; a mold layer over the package substrate and embedding the first die and the second die; and a through mold interconnect through the mold layer; a second package, wherein the second package comprises: a mold layer; a plurality of third dies embedded in the mold layer; and a solder resist on the mold layer, wherein a first surface of the solder resist that faces away from the mold layer comprises a first cavity into the solder resist; and a thermal adhesive between the first package and the second package.

(71) Example 14: the electronic package of Example 13, wherein the thermal adhesive fills the first cavity.

(72) Example 15: the electronic package of Example 13 or Example 14, wherein a footprint of the first cavity covers a footprint of the first die.

(73) Example 16: the electronic package of Examples 13-15 further comprising a second cavity within the first.

(74) Example 17: the electronic package of Example 16, wherein a footprint of the second cavity covers a footprint of the second die.

(75) Example 18: the electronic package of Example 16, wherein a footprint of the second cavity covers a portion of a footprint of the second die.

(76) Example 19: the electronic package of Example 18, wherein the portion of the footprint of the second die that is covered by the footprint of the second cavity is a hotspot of the second die.

(77) Example 20: the electronic package of Examples 13-19, wherein a depth of the first cavity is less than a thickness of the solder resist.

(78) Example 21: the electronic package of Examples 13-20, wherein the first surface has a first surface roughness and a second surface the solder resist within the first cavity has a second surface roughness, and wherein the second surface roughness is greater than the first surface roughness.

- (79) Example 22: the electronic package of Examples 13-21, wherein the first package is a multi-chip processor package, and wherein the second package is a memory package.
- (80) Example 23: the electronic system, comprising: a board; a first package coupled to the board; a second package coupled to the first package, wherein the second package comprises a solder resist with a first cavity into a surface facing the first package; and a thermal adhesive between the first package and the second package, wherein the thermal adhesive fills the first cavity.
- (81) Example 24: the electronic system of Example 23, further comprising: a second cavity within the first cavity.
- (82) Example 25: the electronic system of Example 23, wherein a surface roughness of the solder resist within the first cavity is greater than a surface roughness of the solder resist outside of the first cavity.

Claims

1. An electronic system, comprising: a bottom package comprising a first package substrate having a top side and an opposite bottom side, a first die coupled to the top side of the first package substrate by interconnects, a first mold layer over the first package substrate and in contact with the first die, the first mold layer having an uppermost surface above an uppermost surface of the first die, and through mold interconnects through the first mold layer and laterally adjacent to the first die; a top package coupled to the bottom package, the top package comprising a second package substrate having a top side and an opposite bottom side, a second die above and coupled to the top side of the second package substrate by a first wire bond, and a third die above the second die, the third die coupled to the top side of the second package substrate by a second wire bond, a second mold layer over the second die and the third die and over the second package substrate, and a solder resist layer on the bottom side of the second package substrate, wherein the solder resist has a cavity therein, the cavity having a depth less than a thickness of the solder resist, wherein the second mold layer of the top package has a sidewall in vertical alignment with a sidewall of the first mold layer of the bottom package; interconnects coupled to the bottom side of the first package substrate; and a board coupled to the interconnects.
2. The electronic system of claim 1, wherein the through mold interconnects of the bottom package are in contact with the solder resist layer.
3. The electronic system of claim 1, wherein the second mold layer of the top package has a second sidewall in vertical alignment with a second sidewall of the first mold layer of the bottom package, the second sidewall of the second mold layer of the top package laterally opposite the first sidewall of the second mold layer of the top package, and the second sidewall of the first mold layer of the bottom package laterally opposite the first sidewall of the first mold layer of the bottom package.
4. The electronic system of claim 1, further comprising: a thermal interface material between the bottom package and the solder resist layer.
5. The electronic system of claim 1, further comprising: a fourth die vertically between the first die and the second die.
6. An electronic system, comprising: a first package comprising a first package substrate having a top side and an opposite bottom side, a first die coupled to the top side of the first package substrate by interconnects, a first mold layer over the first package substrate and in contact with the first die, the first mold layer having an uppermost surface above an uppermost surface of the first die, and through mold interconnects through the first mold layer and laterally adjacent to the first die; and a second package coupled to the first package, the second package comprising a second package substrate having a top side and an opposite bottom side, a second die above and coupled to the top side of the second package substrate by a first wire bond, and a third die above the second die, the third die coupled to the top side of the second package substrate by a second wire bond, a second mold layer over the second die and the third die and over the second package substrate, and

a solder resist layer on the bottom side of the second package substrate, wherein the solder resist has a cavity therein, the cavity having a depth less than a thickness of the solder resist, wherein the second mold layer of the second package has a first sidewall in vertical alignment with a first sidewall of the first mold layer of the first package, and wherein the second mold layer of the second package has a second sidewall in vertical alignment with a second sidewall of the first mold layer of the first package, the second sidewall of the second mold layer of the second package laterally opposite the first sidewall of the second mold layer of the second package, and the second sidewall of the first mold layer of the first package laterally opposite the first sidewall of the first mold layer of the first package.

7. The electronic system of claim 6, wherein the through mold interconnects of the first package are in contact with the solder resist layer.

8. The electronic system of claim 6, further comprising: a thermal interface material between the first package and the solder resist layer.

9. The electronic system of claim 6, further comprising: a fourth die vertically between the first die and the second die.

10. The electronic system of claim 6, further comprising: interconnects coupled to the bottom side of the first package substrate.

11. The electronic system of claim 10, further comprising: a board coupled to the interconnects.

12. A method of fabricating an electronic system, comprising: forming a bottom package comprising a first package substrate having a top side and an opposite bottom side, a first die coupled to the top side of the first package substrate by interconnects, a first mold layer over the first package substrate and in contact with the first die, the first mold layer having an uppermost surface above an uppermost surface of the first die, and through mold interconnects through the first mold layer and laterally adjacent to the first die; forming a top package comprising a second package substrate having a top side and an opposite bottom side, a second die above and coupled to the top side of the second package substrate by a first wire bond, and a third die above the second die, the third die coupled to the top side of the second package substrate by a second wire bond, a second mold layer over the second die and the third die and over the second package substrate, and a solder resist layer on the bottom side of the second package substrate, wherein the solder resist has a cavity therein, the cavity having a depth less than a thickness of the solder resist, wherein the second mold layer of the top package has a sidewall in vertical alignment with a sidewall of the first mold layer of the bottom package; and coupling the top package coupled to the bottom package.

13. The method of claim 12, further comprising: forming interconnects coupled to the bottom side of the first package substrate.

14. The method of claim 13, further comprising: coupling a board coupled to the interconnects.

15. The method of claim 12, wherein the through mold interconnects of the bottom package are in contact with the solder resist layer.

16. The method of claim 12, wherein the second mold layer of the top package has a second sidewall in vertical alignment with a second sidewall of the first mold layer of the bottom package, the second sidewall of the second mold layer of the top package laterally opposite the first sidewall of the second mold layer of the top package, and the second sidewall of the first mold layer of the bottom package laterally opposite the first sidewall of the first mold layer of the bottom package.

17. The method of claim 12, further comprising: forming a thermal interface material between the bottom package and the solder resist layer.
