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TSV AS PAD

Abstract

Representative techniques and devices including process steps may be employed to mitigate the potential for delamination of bonded microelectronic substrates due to metal expansion at a bonding interface. For example, a through-silicon via (TSV) may be disposed through at least one of the microelectronic substrates. The TSV is exposed at the bonding interface of the substrate and functions as a contact surface for direct bonding.

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Background/Summary

PRIORITY CLAIM AND CROSS-REFERENCE TO RELATED APPLICATION [0001] This application is a continuation of U.S. patent application Ser. No. 18/451,674, filed Aug. 17, 2023, which is a continuation of U.S. patent application Ser. No. 16/439,360, filed Jun. 12, 2019, which claims the benefit under 35 U.S.C. § 119(e)(1) of U.S. Provisional Application No. 62/684,505, filed Jun. 13, 2018, which are hereby incorporated by reference in their entireties.

FIELD

[0002] The following description relates to integrated circuits (“ICs”). More particularly, the following description relates to manufacturing IC dies and wafers.

BACKGROUND

[0003] Microelectronic elements often comprise a thin slab of a semiconductor material, such as silicon or gallium arsenide, commonly called a semiconductor wafer. A wafer can be formed to include multiple integrated chips or dies on a surface of the wafer and/or partly embedded within the wafer. Dies that are separated from a wafer are commonly provided as individual, prepackaged units. In some package designs, the die is mounted to a substrate or a chip carrier, which is in turn mounted on a circuit panel, such as a printed circuit board (PCB). For example, many dies are provided in packages suitable for surface mounting.

[0004] Packaged semiconductor dies can also be provided in “stacked” arrangements, wherein one package is provided, for example, on a circuit board or other carrier, and another package is mounted on top of the first package. These arrangements can allow a number of different dies or devices to be mounted within a single footprint on a circuit board and can further facilitate high-speed operation by providing a short interconnection between the packages. Often, this interconnect distance can be only slightly larger than the thickness of the die itself. For interconnection to be achieved within a stack of die packages, interconnection structures for mechanical and electrical connection may be provided on both sides (e.g., faces) of each die package (except for the topmost package).

[0005] Additionally, dies or wafers may be stacked in a three-dimensional arrangement as part of various microelectronic packaging schemes. This can include stacking a layer of one or more dies, devices, and/or wafers on a larger base die, device, wafer, substrate, or the like, stacking multiple dies or wafers in a vertical or horizontal arrangement, and various combinations of both.

[0006] Dies or wafers may be bonded in a stacked arrangement using various bonding techniques, including direct dielectric bonding, non-adhesive techniques, such as ZiBond® or a hybrid bonding technique, such as DBI®, both available from Invensas Bonding Technologies, Inc. (formerly Ziptronix, Inc.), an Xperi company. The bonding includes a spontaneous process that takes place at ambient conditions when two prepared surfaces are brought together (see for example, U.S. Pat. Nos. 6,864,585 and 7,485,968, which are incorporated herein in their entirety).

[0007] Respective mating surfaces of the bonded dies or wafers often include embedded conductive interconnect structures (which may be metal), or the like. In some examples, the

bonding surfaces are arranged and aligned so that the conductive interconnect structures from the respective surfaces are joined during the bonding. The joined interconnect structures form continuous conductive interconnects (for signals, power, etc.) between the stacked dies or wafers. [0008] There can be a variety of challenges to implementing stacked die and wafer arrangements. When bonding stacked dies using a direct bonding or hybrid bonding technique, it is usually desirable that the surfaces of the dies to be bonded be extremely flat, smooth, and clean. For instance, in general, the surfaces should have a very low variance in surface topology (i.e., nanometer scale variance), so that the surfaces can be closely mated to form a lasting bond.

[0009] Double-sided dies can be formed and prepared for stacking and bonding, where both sides of the dies will be bonded to other substrates or dies, such as with multiple die-to-die or die-to-wafer applications. Preparing both sides of the die includes finishing both surfaces to meet dielectric roughness specifications and metallic layer (e.g., copper, etc.) recess specifications. For instance, conductive interconnect structures at the bonding surfaces may be slightly recessed, just below the insulating material of the bonding surface. The amount of recess below the bonding surface may be determined by a dimensional tolerance, specification, or physical limitation of the device or application. The hybrid surface may be prepared for bonding with another die, wafer, or other substrate using a chemical mechanical polishing (CMP) process, or the like.

[0010] In general, when direct bonding surfaces containing a combination of a dielectric layer and one or more metal features (e.g., embedded conductive interconnect structures) are bonded together, the dielectric surfaces bond first at lower temperatures and the metal of the features expands afterwards, as the metal is heated during annealing. The expansion of the metal can cause the metal from both bonding surfaces to join into a unified conductive structure (metal-to-metal bond). While both the substrate and the metal are heated during annealing, the coefficient of thermal expansion (CTE) of the metal relative to the CTE of the substrate generally dictates that the metal expands much more than the substrate at a particular temperature (e.g., -300°C). For instance, the CTE of copper is 16.7, while the CTE of fused silica is 0.55, and the CTE of silicon is 2.56.

[0011] In some cases, the greater expansion of the metal relative to the substrate can be problematic for direct bonding stacked dies or wafers. If a metal pad is positioned over a through-silicon via (TSV), the expansion of the TSV metal can contribute to the expansion of the pad metal. In some cases, the combined metal expansion can cause localized delamination of the bonding surfaces, as the expanding metal rises above the bonding surface. For instance, the expanded metal can separate the bonded dielectric surfaces of the stacked dies.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The detailed description is set forth with reference to the accompanying figures. In the figures, the left-most digit(s) of a reference number identifies the figure in which the reference number first appears. The use of the same reference numbers in different figures indicates similar or identical items.

[0013] For this discussion, the devices and systems illustrated in the figures are shown as having a multiplicity of components. Various implementations of devices and/or systems, as described herein, may include fewer components and remain within the scope of the disclosure. Alternatively, other implementations of devices and/or systems may include additional components, or various combinations of the described components, and remain within the scope of the disclosure.

[0014] FIG. 1A shows a cross-section of an example substrate with bonding pads and a TSV.

[0015] FIG. 1B shows a top view of the example substrate of FIG. 1A.

[0016] FIG. 2 shows a cross-section of two example bonded substrates with bonding pads and TSVs, and example resulting delamination.

[0017] FIG. 3A shows a cross-section of an example substrate with at least one end of the TSV as a bonding surface, according to an embodiment.

[0018] FIG. 3B shows a top view of the example substrate of FIG. 3A, according to an embodiment.

[0019] FIG. 4 shows a cross-section of two example bonded substrates with at least one end of the TSV as a bonding surface, according to an embodiment.

[0020] FIG. 5 shows a cross-section of two example substrates with at least one end of the TSV as a bonding surface, according to an embodiment.

[0021] FIG. 6 shows a cross-section of two example substrates with at least one end of the TSV as a bonding surface, the bonding surfaces having an uneven surface, according to an embodiment.

[0022] FIGS. 7-13 show a cross-section of an example substrate with at least one end of the TSV as a bonding surface, illustrating an example backside process of the substrate, according to an embodiment.

[0023] FIG. 14 shows a diagram of example TSVs used for heat management of a die, according to various embodiments.

[0024] FIG. 15 is a text flow diagram illustrating an example process of forming a microelectronic assembly to reduce or eliminate delamination of the bonded substrates, according to an embodiment.

SUMMARY

[0025] Representative techniques and devices are disclosed, including process steps for preparing various microelectronic devices for bonding, such as for direct bonding without adhesive. In various embodiments, techniques may be employed to mitigate the potential for delamination due to metal expansion, particularly when a TSV or a bond pad over a TSV is presented at the bonding surface of one or both devices to be bonded. For example, in one embodiment, the TSV may extend partially or fully through the substrate of the device, and at least one end of the TSV is exposed at a bonding surface of the device. For instance, the exposed end of the TSV is prepared and used as a bonding surface or in place of a bonding pad for the device.

[0026] When using surface preparation processes such as CMP to prepare the bonding surface of the substrate, an exposed metal end of the TSV at the bonding surface can become recessed relative to the dielectric, due to the softer material of the TSV relative to the material of the dielectric. A larger diameter TSV may become recessed to a greater degree (e.g., a deeper recess) than a smaller diameter TSV. In such an embodiment, the recess of the end surface of the TSV provides room for the metal expansion of the TSV during heated annealing, which can reduce or eliminate delamination that could occur otherwise.

[0027] In various implementations, an example process includes providing a conductive via through a first substrate having a first bonding surface. The conductive via extends from the first bonding surface at least partially through the first substrate. The process includes exposing the conductive via from a surface opposite the first bonding surface, and forming a second bonding surface with the conductive via at or recessed relative to the second bonding surface.

[0028] In various embodiments, the process includes reducing or eliminating delamination of bonded microelectronic components by selecting the conductive via and using at least one end of the conductive via as a bonding contact surface for direct bonding (e.g., DBI).

[0029] Additionally or alternatively, the back side of the first substrate may also be processed for bonding. One or more insulating layers of preselected materials may be deposited on the back side of the first substrate to provide stress relief when the back side of the first substrate is to be direct bonded.

[0030] Further, the conductive via, as well as other conductive vias within the first substrate may be used to direct or transfer heat within the first substrate and/or away from the first substrate. In some implementations, the thermal transfer conductive vias may extend partially or fully through a thickness of the first substrate and may include a thermally conductive barrier layer. In such

examples, barrier layers normally used around the conductive vias that tend to be thermally insulating may be replaced with thermally conductive layers instead. In various implementations, some conductive vias may be used for signal transfer and thermal transfer.

[0031] In an embodiment, a microelectronic assembly comprises a first substrate having a front side and a back side, where the back side has a bonding surface comprising a nonconductive bonding layer and a conductive via. A second substrate has a front side and a back side, and the front side includes a nonconductive bonding layer and a conductive feature. The front side of the second substrate is direct bonded to the back side of the first substrate such that the conductive pad contacts to the conductive feature. An exposed end of the conductive via comprises a contact surface suitable for direct metal-to-metal bonding without an intervening material.

[0032] Various implementations and arrangements are discussed with reference to electrical and electronics components and varied carriers. While specific components (i.e., dies, wafers, integrated circuit (IC) chip dies, substrates, etc.) are mentioned, this is not intended to be limiting, and is for ease of discussion and illustrative convenience. The techniques and devices discussed with reference to a wafer, die, substrate, or the like, are applicable to any type or number of electrical components, circuits (e.g., integrated circuits (IC), mixed circuits, ASICs, memory devices, processors, etc.), groups of components, packaged components, structures (e.g., wafers, panels, boards, PCBs, etc.), and the like, that may be coupled to interface with each other, with external circuits, systems, carriers, and the like. Each of these different components, circuits, groups, packages, structures, and the like, can be generically referred to as a “microelectronic component.” For simplicity, unless otherwise specified, components being bonded to another component will be referred to herein as a “die.”

[0033] This summary is not intended to give a full description. Implementations are explained in more detail below using a plurality of examples. Although various implementations and examples are discussed here and below, further implementations and examples may be possible by combining the features and elements of individual implementations and examples.

DETAILED DESCRIPTION

Overview

[0034] Referring to FIG. 1A (showing a cross-sectional profile view) and FIG. 1B (showing a top view), patterned metal and oxide layers are frequently provided on a die, wafer, or other substrate (hereinafter “die **102**”) as a hybrid bonding, or DBI®, surface layer. A representative device die **102** may be formed using various techniques, to include a base substrate **104** and one or more insulating or dielectric layers **106**. The base substrate **104** may be comprised of silicon, germanium, glass, quartz, a dielectric surface, direct or indirect gap semiconductor materials or layers or another suitable material. The insulating layer **106** is deposited or formed over the substrate **104**, and may be comprised of an inorganic dielectric material layer such as oxide, nitride, oxynitride, oxycarbide, carbides, carbonitrides, diamond, diamond like materials, glasses, ceramics, glass-ceramics, and the like.

[0035] A bonding surface **108** of the device wafer **102** can include conductive features such as contact pads **110**, traces **112**, and other interconnect structures, for example, embedded into the insulating layer **106** and arranged so that the conductive features **110** from respective bonding surfaces **108** of opposing devices can be mated and joined during bonding, if desired. The joined conductive features **110** can form continuous conductive interconnects (for signals, power, etc.) between stacked devices.

[0036] Damascene processes (or the like) may be used to form the embedded conductive features **110** in the insulating layer **106**. The conductive features **110** may be comprised of metals (e.g., copper, etc.) or other conductive materials, or combinations of materials, and include structures, traces, pads, patterns, and so forth. In some examples, a barrier layer may be deposited in the cavities for the conductive features **110** prior to depositing the material of the conductive features **110**, such that the barrier layer is disposed between the conductive features **110** and the insulating

layer **106**. The barrier layer may be comprised of tantalum, for example, or another conductive material, to prevent or reduce diffusion of the material of the conductive features **110** into the insulating layer **106**. After the conductive features **110** are formed, the exposed surface of the device wafer **102**, including the insulating layer **106** and the conductive features **110** can be planarized (e.g., via CMP) to form a flat bonding surface **108**.

[0037] Forming the bonding surface **108** includes finishing the surface **108** to meet dielectric roughness specifications and metallic layer (e.g., copper, etc.) recess specifications, to prepare the surface **108** for direct bonding. In other words, the bonding surface **108** is formed to be as flat and smooth as possible, with very minimal surface topology variance. Various conventional processes, such as chemical mechanical polishing (CMP), dry or wet etching, and so forth, may be used to achieve the low surface roughness. These processes provides the flat, smooth surface **108** that results in a reliable bond.

[0038] In the case of double-sided dies **102**, a patterned metal and insulating layer **106** with prepared bonding surfaces **108** may be provided on both sides of the die **102**. The insulating layer **106** is typically highly planar (usually to nm-level roughness) with the metal layer (e.g., embedded conductive features **110**) at or recessed just below the bonding surface **108**. The amount of recess below the surface **108** of the insulating layer **106** is typically determined by a dimensional tolerance, specification, or physical limitation. The bonding surfaces **108** are often prepared for direct bonding with another die, wafer, or other substrate using a chemical-mechanical polishing (CMP) step and/or other preparation steps.

[0039] Some embedded conductive features or interconnect structures may comprise metal pads **110** or conductive traces **112** that extend partially into the dielectric substrate **106** below the prepared surface **108**. For instance, some patterned metal (e.g., copper) features **110** or **112** may be about 0.5-2 microns thick. The metal of these features **110** or **112** may expand as the metal is heated during annealing. Other conductive interconnect structures may comprise metal (e.g., copper) through silicon vias (TSVs) **114** or the like, that extend normal to the bonding surface **108**, partly or fully through the substrate **102** and include a larger quantity of metal. For instance, a TSV **114** may extend about 50 microns, depending on the thickness of the substrate **102**. The metal of the TSV **114** may also expand when heated. Pads **110** and/or traces **112** may or may not be electrically coupled to TSVs **114**, as shown in FIG. 1A.

[0040] Referring to FIG. 2, dies **102** may be direct bonded, for instance, without adhesive to other dies **102** with metal pads **110**, traces **112**, and/or TSVs **114**. If a metal pad **110** is positioned over a TSV **114** (overlapping and physically and electrically coupled to the TSV **114**), the expansion of the TSV **114** metal can contribute to the expansion of the pad **110** metal. In some cases, the combined metal expansion can cause localized delamination **202** of the bonding surfaces at the location of the TSV **114** (or TSV **114**/pad **110** combination), as the expanding metal rises above the bonding surface **108**. For instance, the expanded metal can separate the bonded dielectric surfaces **108** of the stacked dies **102**.

EXAMPLE EMBODIMENTS

[0041] Referring to FIGS. 3A-6, in various embodiments, techniques may be employed to mitigate the potential for delamination due to metal expansion. For example, in one embodiment, as shown in FIGS. 3A and 3B, a TSV **114** may be extended through the base layer **104** of the die **102**, and through one or more insulating layers **106** to at least one bonding surface **108**. An end **302** (or both ends **302**) of the TSV **114** may be exposed at the bonding surface(s) **108** of the die **102** and used as a contact surface for direct bonding (e.g., DBI). In other words, the contact surface **302** of the TSV can be exposed through the dielectric layer **106** at the bonding surface, prepared (e.g., planarized, etc.), and used in place of a direct bonding pad (instead of a contact pad **110**).

[0042] Referring to FIG. 4, in various implementations, using an end surface **302** of the TSV **114** as a bonding surface can reduce or eliminate delamination of bonded dies **102**, when the dies **102** are heat annealed and the metal of the TSV **114** and the contact pads **110** expand. In the

implementations, the metal expansion of the TSV **114** may be taken into consideration, based on the volume of the TSV **114**. Accordingly, a predetermined recess “d” in the end surface **302** of the TSV **114** (as shown in FIG. 5, for example) can be sufficient to provide room for the material expansion of the TSV **114**.

[0043] In various embodiments, TSVs **114** used as direct bonding contact structures may have diameters that are larger or smaller by a preselected amount, than other TSVs **114** disposed elsewhere within the die **102**. In an embodiment, the size of the TSVs **114** are selected or formed by estimating an amount that the material of the TSV **114** will expand when heated to a preselected temperature (-300°), based on a volume of the material of the TSV **114** and a coefficient of thermal expansion (CTE) of the material of the TSV **114**, and predicting an amount that the material of the TSV **114** will expand when heated to the preselected temperature.

[0044] Referring to FIG. 5, in an embodiment, the end **302** of the TSV **114** is planarized along with the bonding surface **108** of the dielectric layer **106**, including recessing the end **302** of the TSV **114** to have a predetermined recess depth (“d”) relative to the bonding surface **108**, based on an expansion of the TSV **114** material at the predetermined temperature. In other words, the recess depth is determined based on the volume of the material of the TSV **114** and the coefficient of thermal expansion (CTE) of the material of the TSV **114**.

[0045] In one embodiment, the end **302** of a TSV **114** may be selectively etched (via acid etching, plasma oxidation, etc.) to provide the desired recess depth “d” (to accommodate a predicted metal expansion). In another example, as shown at FIG. 6, the end **302** of a corresponding TSV **114** may be selected, formed, or processed to have an uneven top surface as an expansion buffer. For example, referring to FIG. 6, the end surface **302** of the TSV **114** may be formed or selectively etched to be rounded, domed, convex, concave, irregular, or otherwise non-flat to allow additional space **602** for material expansion.

[0046] The additional space **602** may be determined and formed based on the amount that the material of the TSV **114** will expand when heated. In various implementations, the end surface **302** of the TSV **114** may be formed to be uneven during deposition, or may be etched, grinded, polished, or otherwise made uneven after forming the TSV **114**. In some cases, the end surface **302** of the TSV **114** may be made uneven during CMP of the bonding surface **108**.

[0047] Additionally or alternately, the dielectric **106** at the bonding surface **108** around the TSV **114** can be formed or shaped to allow room for the metal of the TSV **114** to expand. In one example, a CMP process can be used to shape the surface **108** of the dielectric **106** around the TSV **114**, or in other examples other processes can be used, so that the dielectric **106** around the TSV **114** includes a recess or other gap that provides room for metal expansion. In an embodiment, the dielectric **106** can be recessed (e.g., with CMP) while the bonding surface **108** is being prepared. In the embodiment, the TSV **114** and the dielectric **106** may be recessed concurrently (but at different rates). For instance, the process may form erosion in the dielectric **106** around the edges of the TSV **114** while recessing the metal TSV **114**.

[0048] In various embodiments, the TSV **114** is comprised of copper, a copper alloy, or the like. In a further embodiment, the materials of the TSV **114** may be varied to control metal expansion and potential resulting delamination. For instance, in some embodiments, the TSV **114** may be comprised of different conductive materials, perhaps with lower CTEs. In some embodiments the TSV **114** may be comprised of a different conductive material (with a lower CTE) than the contact pads **110**. For example, the TSV **114** may be comprised of tungsten, an alloy, or the like.

[0049] In other embodiments the volume of material of the TSV **114** may be varied to control metal expansion and the potential for resulting delamination. For instance, in some embodiments, a TSV **114** with a preselected material volume (e.g., less volume of material) may be used, when this is allowable within the design specifications. The preselection of volume of the TSV **114** may be based on anticipated material expansion of the TSV **114**.

[0050] Referring back to FIG. 4, after preparation of the bonding surface **108** (e.g., by CMP) the

die **102** may be direct bonded, for instance, without adhesive to other dies **102** with metal pads **110**, traces **112**, and/or TSVs **114**. The material of the TSVs **114** expand during heated annealing as mating TSVs **114** of opposite dies **102** bond to form a single conductive interconnect. However, the metal expansion does not cause delamination of the bonding surfaces when an adequate predetermined recess is provided as discussed, since the expanding metal of the TSV **114** does not exceed the space provided by the recess at the end surface **302** of the TSV **114**.

[0051] For instance, if the end surface **302** of the TSVs **114** are sufficiently recessed, the expanding metal of the TSVs **114** fills the recess(es) without separating the bonded dielectric surfaces **108** of the stacked dies **102**. When using surface preparation processes such as CMP to prepare the bonding surface **108** of the die **102**, the TSVs **114** exposed at the bonding surface **108** can become recessed (intentionally or unintentionally) relative to the dielectric **106**, due to the softness of the TSVs **114** (which may comprise copper, for instance) relative to the dielectric **106** (which may comprise an oxide, for example).

[0052] In various embodiments, the amount of recessing of a TSV **114** may be predictable, based on the surface preparation technique used (e.g., the chemical combination used, the speed of the polishing equipment, etc.), the materials of the dielectric layer **106** and the TSV **114**, the spacing or density of the TSVs **114** (and metal pads **110**), and the size (e.g., area or diameter) of the TSVs **114**. In the embodiments, the area or diameter of the TSVs **114** may be selected (e.g., for a particular material) to avoid delamination of bonded dies **102** based on the recess desired and the expected metal expansion of the TSVs **114**. For example, in some cases, larger diameter TSVs **114** may be selected when increased recessing is desired. This technique can result in reduced or eliminated delamination, as well as dependable mechanical coupling of the dielectric **106** and metal structures (e.g., TSVs **114**) at the bonding surfaces **108** and reliable electrical continuity of the bonded metal structures.

Additional Embodiments

[0053] FIGS. 7-13 illustrate examples of backside die **102** processing, according to various embodiments. In some implementations, where dies **102** are stacked and direct bonded without adhesive, the backside **702** of the die **102** may receive different preparation than the top-side bonding surface **108**, when the backside **702** is prepared for direct bonding. Instead of forming the dielectric layer **106** on the backside **702** of the die **102**, the backside **702** may be prepared differently to reduce process steps, reduce manufacturing costs, or for other reasons.

[0054] In one implementation, the backside **702** is prepared so that the TSV **114** is exposed, to be used as a contact surface **302** for bonding to a conductive pad, interconnect, or other conductive bonding surface. The preparation may include depositing a thin layer of insulating material and planarizing (via CMP, for example) the backside **702** (which may include planarizing the insulating material and/or the base substrate **104**) to reveal the TSV **114**. In some cases, however, the expansion of the material of the TSV **114** during heated annealing can cause the insulating material and/or the substrate **104** to become damaged.

[0055] In an embodiment, as shown in FIGS. 7-13, one or more layers of material may be deposited on the backside **702** as a stress relief to prevent or eliminate damage to the substrate **104** and the die **102**. The layers of material can be planarized and otherwise prepared as a bonding surface on the backside **702** of the die **102**.

[0056] As shown at FIG. 7 the TSV **114** is disposed within the die **102**, transverse to the bonding surface **108** of the die **102**. The TSV **114** may initially extend beyond the surface of the backside **702** of the die **102**. A diffusion barrier and oxide liner **704** surrounds the TSV **114** to prevent diffusion of the metal of the TSV **114** (e.g., copper) into the material of the base substrate **104** (e.g., silicon). In an embodiment, as shown at FIG. 7, another diffusion barrier **706** is deposited on the surface of the backside **702** of the die **102**. In an example, the diffusion barrier **706** comprises a dielectric, such as a nitride or the like.

[0057] In various embodiments, one or more insulating layers are then deposited onto the backside

702 of the die **102** to prevent damage to the die **102** when the material of the TSV **114** expands. For example, a first layer **708**, comprising a first low temperature dielectric, such as an oxide, may be deposited over the backside **702**, including over the diffusion layer **706**. The first oxide layer **708** may comprise a low temperature oxide bonding layer. For instance, FIG. 7 shows this scenario, and includes a formed contact pad **110** on the front side bonding surface **108** over the TSV **114**. [0058] As shown at FIG. 8, the backside **702** is planarized (via CMP, for example), including the one or more insulating layers **708** to form a flat, smooth bonding surface for direct bonding. The remaining dielectric layer **708** can assist with warpage control, balancing with the front side of the die **102**. The TSV **114** is exposed by the planarizing, including a revealed contact surface **302** of the TSV **114**.

[0059] Notably, when some types of low temperature oxide (e.g., silox, etc.) are used, the oxide may be less rigid and the TSV **114** may be more prone to breaking during planarization. Once planarized, the oxide is more stable. When other types of low temperature oxide (e.g., TEOS, etc.) are used, the oxide may give better support to the TSV **114**, but the oxide may also relax, leaving the area around the TSV **114** higher (−1-10 nm) than the bonding surface, which can cause problems with direct bonding (e.g., DBI). As a solution to this issue, the DBI bonding layer (the layer **708**, for example) is added on top of the TSV **114**, as shown in FIG. 7.

[0060] A second die **802** similar or identical to the die **102** is also shown at FIG. 8, in dashed lines. The illustration of FIG. 8 shows an example of a front-to back direct bonding arrangement (without adhesive), where the second die **802** is bonded (dielectric-to-dielectric) at the front side **108** of the second die **802** to the backside **702** of the first die **102**. As shown, in such an arrangement, the surface **302** of the revealed TSV **114** at the backside **702** of the first die **102** is bonded (metal-to-metal) to the conductive pad **110** at the second die **802**. In alternate embodiments, the dies **102** and **802** may be bonded front-to-front, or back-to-back.

[0061] In an embodiment, as shown at FIGS. 9-10, multiple layers may be added to the backside **702** to reduce metal expansion stress at the TSV **114** and to form a backside **702** bonding surface for the die **102**. As shown at FIG. 9, after deposition of the first low temperature oxide layer **708** (which also comprises the bonding layer in some implementations), a second dielectric layer **902** (which may comprise a low temperature oxide) may be deposited over the first layer **708**. No barrier or adhesion layer is needed between the two oxide layers (**708** and **902**). In various implementations, the first layer **708** and the second layer **902** are comprised of similar or the same materials (in varying thicknesses). In other implementations, the first layer **708** and the second layer **902** are comprised of different materials. The second oxide layer **902** may have a similar or a different residue stress characteristic than the first layer **708** (for example, the first layer **708** may be compressive and the second layer **902** may be tensile, or vice versa, or both layers **708** and **902** may be compressive or tensile with similar or different values). In alternate implementations, additional insulating layers may also be deposited over the first **708** and second **902** layers.

[0062] As shown at FIG. 10, the layers **708** and **902** are planarized (e.g., CMP), revealing the TSV **114** and the end surface **302**, which can function in place of a bonding pad. In an implementation, part of the second layer **902** may be left on the die **102** for warpage control.

[0063] In some embodiments, as shown in FIG. 11, the end surface **302** at the backside **702** may be formed to have an uneven or non-flat surface topology. For example, the end surface **302** may be selected, formed, or processed to have an uneven surface topology as an expansion buffer. For example, referring to FIG. 11, the end surface **302** of the TSV **114** may be formed or selectively etched to be rounded, domed, convex, concave, irregular, or otherwise non-flat to allow additional space **1102** for material expansion.

[0064] The additional space **1102** may be determined and formed based on the prediction of the amount that the material of the TSV **114** will expand when heated. In various implementations, the end surface **302** of the TSV **114** may be formed to be uneven during deposition, or may be etched, grinded, polished, or otherwise made uneven after forming the TSV **114**. In some cases, the end

surface **302** of the TSV **114** may be made uneven during CMP of the backside **702** bonding surface. [0065] FIGS. **12-13** illustrate examples of processing the backside **702** of the die **102**, when an offset contact pad **110** is disposed on the front side **108**, according to various embodiments. As shown in FIGS. **12** and **13**, the offset contact pad **110** may be coupled to the TSV **114** using one or more traces **112**, or the like. As discussed above, one or more oxide stress layers (such as layer **708**, for example) may be deposited on the backside **702** after depositing a diffusion barrier layer **706** over the backside **702**. The stress layer **708** may also comprise a direct bonding layer when it is the final layer on the backside **702**.

[0066] As shown in FIG. **13**, the layer **708** is planarized to form a bonding surface and to reveal the TSV **114** with a smooth contact surface **302**. In alternate embodiments, multiple stress layers may be deposited and planarized at the backside **702** in preparation for direct bonding.

[0067] In other embodiments, alternate techniques may be used to reduce or eliminate delamination due to metal feature expansion, and remain within the scope of the disclosure.

[0068] In various embodiments, as illustrated at FIG. **14**, one or more of the TSVs **114** of a set of stacked dies **102** may be used to conduct heat in addition to or instead of electrical signals. For example, in some cases, it may not be practical or possible to attach a heat sink (or other heat transfer device) to a die **102** of a set of stacked dies **102** to alleviate heat generated by the die **102**. In such cases, other techniques may be looked-for to transfer heat as desired.

[0069] In the embodiments, as shown at FIG. **14**, various configurations of TSVs **114**, including TSVs **114** that extend partially or fully through a die **102**, may be employed to conduct heat away from the dies **102** (or away from a heat-generating portion of the dies **102**). The TSVs **114** of one die **102** may be used in conjunction with TSVs **114**, contact pads **110**, traces **112**, and the like, of the second die **102** to complete heat transfer from one die **102** to the other die **102**, and so forth. The TSVs **114** of the first die **102** can be direct bonded (e.g., DBI) to the TSVs **114**, contact pads **110**, traces **112**, and the like of the second die **102** for high performance thermal conductivity.

[0070] In an implementation, some of the TSVs **114**, contact pads **110**, traces **112**, and the like are electrically floating or “dummy” structures, which can be used for thermal transfer. These structures may conduct heat away from a high power die **102** to another die **102** or substrate as desired. Dummy contact pads **110** may be coupled to via last or via mid thermal TSVs **114** for thermal conduction.

[0071] In the embodiments, diffusion barrier layers **704**, which surround the TSVs **114** and can be thermally restrictive or thermal barriers may be replaced by diffusion barriers of a different material having some thermal conductivity (such as metal or alloy barriers, or the like).

Example Process

[0072] FIG. **15** illustrates a representative process **1500** for preparing various microelectronic components (such as dies **102**, for example) for bonding, such as for direct bonding without adhesive, while reducing or eliminating the potential for delamination due to metal expansion of embedded structures at the bonding surface. For instance, through-silicon vias (TSVs) at the bonding surface may cause delamination, particularly when coupled to contact pads, as the material of the TSVs and the contact pads expands during heated annealing. The process refers to FIGS. **1-14**.

[0073] The order in which the process is described is not intended to be construed as limiting, and any number of the described process blocks in the process can be combined in any order to implement the process, or alternate processes. Additionally, individual blocks may be deleted from the process without departing from the spirit and scope of the subject matter described herein. Furthermore, the process can be implemented in any suitable hardware, software, firmware, or a combination thereof, without departing from the scope of the subject matter described herein. In alternate implementations, other techniques may be included in the process in various combinations and remain within the scope of the disclosure.

[0074] In various implementations, a die, wafer, or other substrate (a “substrate”) is formed using

various techniques to include a base substrate and one or more dielectric layers. In an implementation, at block **1502**, the process **1500** includes providing a conductive via (such as TSV **114**, for example) through a first substrate having a first bonding surface (such as bonding surface **108**, for example), the conductive via extending from the first bonding surface at least partially through the first substrate. In an implementation, the first via extends at least partially through the first substrate, normal to the first bonding surface. In one example, the first via extends through the first substrate to one or both surfaces of the first substrate.

[0075] At block **1504**, the process includes exposing the conductive via from a surface opposite the first bonding surface. In an implementation, the process includes forming a recess in an exposed end of the conductive via extending a predetermined depth below the second bonding surface. For example, the recess compensates for the expansion of the conductive via during a bonding process.

[0076] In one example, the process includes forming the exposed end of the conductive via such that there is a sloped gap between the conductive via and the second bonding surface. In various examples, the uneven topology creates space for via metal expansion during heated annealing.

[0077] At block **1506**, the process includes forming a second bonding surface with the conductive via at or recessed relative to the second bonding surface.

[0078] In an implementation, the process includes providing a second substrate and direct bonding the second bonding surface of the first substrate to the second substrate without an intervening adhesive. In an implementation, the process includes direct bonding the first substrate to the second substrate using a direct dielectric-to-dielectric, non-adhesive bonding technique at a bonding surface of the first substrate.

[0079] In an implementation, the second substrate further includes a conductive via extending at least partially therethrough. In another implementation, the second substrate further includes a pad over the conductive via of the second substrate, the pad contacting the conductive via of the first substrate. In an embodiment, the conductive via of the first substrate is substantially aligned with the conductive via of the second substrate.

[0080] In an alternate implementation, the conductive via is configured to remove heat from the first substrate.

[0081] In various embodiments, some process steps may be modified or eliminated, in comparison to the process steps described herein.

[0082] The techniques, components, and devices described herein are not limited to the illustrations of FIGS. **1-15**, and may be applied to other designs, types, arrangements, and constructions including with other electrical components without departing from the scope of the disclosure. In some cases, additional or alternative components, techniques, sequences, or processes may be used to implement the techniques described herein. Further, the components and/or techniques may be arranged and/or combined in various combinations, while resulting in similar or approximately identical results.

CONCLUSION

[0083] Although the implementations of the disclosure have been described in language specific to structural features and/or methodological acts, it is to be understood that the implementations are not necessarily limited to the specific features or acts described. Rather, the specific features and acts are disclosed as representative forms of implementing example devices and techniques.

Claims

1. (canceled)

2. A microelectronic structure having a back side, the microelectronic structure comprising: a semiconductor base substrate; an electrically conductive via partly or fully through the semiconductor base substrate and exposed at the back side of the microelectronic structure; a dielectric layer having a first portion extending over the semiconductor base substrate and a second

portion extending from the first portion along a portion of the electrically conductive via; an insulating layer over the first portion of the dielectric layer, wherein the second portion of the dielectric layer is between the insulating layer and the portion of the electrically conductive via; and a bonding surface at the back side of the microelectronic structure at least partially defined by an exposed end portion of the electrically conductive via, and a nonconductive bonding layer including a surface of the insulating layer.

3. The microelectronic structure of claim 2, wherein the bonding surface is a direct bonding surface.

4. The microelectronic structure of claim 3, wherein the insulating layer is activated at the bonding surface.

5. The microelectronic structure of claim 2, wherein the dielectric layer comprises a diffusion barrier.

6. The microelectronic structure of claim 2, wherein the nonconductive bonding layer further comprises a surface of the second portion of the dielectric layer.

7. A bonded structure comprising: the microelectronic structure of claim 2; and a second substrate having a front side and a back side, the front side including a nonconductive bonding layer and an exposed pad, wherein the nonconductive bonding layer of the front side of the second substrate is bonded to the nonconductive bonding layer of the back side of the first substrate, and wherein the exposed pad of the second substrate is bonded to the exposed end portion of the electrically conductive via.

8. The bonded structure of claim 7, wherein the second substrate is hybrid bonded to the microelectronic structure, without an intervening adhesive.

9. The bonded structure of claim 7 wherein the exposed pad is embedded at least partially in the second substrate.

10. The bonded structure of claim 7, further comprising a second electrically conductive via partly or fully through a semiconductor material of the second substrate.

11. The bonded structure of claim 10, wherein the second electrically conductive via is in electrical communication with the exposed pad.

12. The bonded structure of claim 11, wherein the second electrically conductive via of the second substrate is in electrical communication with the electrically conductive via of the microelectronic structure.

13. A microelectronic structure having a back side, the microelectronic structure comprising: a semiconductor base substrate; an electrically conductive via partly or fully through the semiconductor base substrate and exposed at the back side of the microelectronic structure; a first dielectric layer having a first portion extending over the semiconductor base substrate and a second portion extending from the first portion along a portion of the electrically conductive via; a second dielectric layer having a first portion extending over the first portion of the first dielectric layer and a second portion extending from the first portion along the second portion of the first dielectric layer; an insulating layer over the first portion of the second dielectric layer, wherein the second portion of the first dielectric layer and the second portion of the second dielectric layer are between the insulating layer and the portion of the electrically conductive via; and a bonding surface at the back side of the microelectronic structure at least partially defined by an exposed end portion of the electrically conductive via, and a nonconductive bonding layer including a surface of the second portion of the first dielectric layer, a surface of the second portion of the second dielectric layer and a surface of the insulating layer.

14. The microelectronic structure of claim 13, wherein the bonding surface is a direct bonding surface.

15. The microelectronic structure of claim 13, wherein the first dielectric layer comprises a diffusion barrier.

16. The microelectronic structure of claim 13, wherein the second dielectric layer comprises silicon

oxide.

17. The microelectronic structure of claim 13, wherein the second dielectric layer comprises a different material compared to the insulating layer.

18. The microelectronic structure of claim 13, wherein the second dielectric layer and the insulating layer comprise the same material.

19. The microelectronic structure of claim 13, wherein the second dielectric layer is in direct contact with the insulating layer.

20. The microelectronic structure of claim 13, wherein the second dielectric layer and the insulating layer have different residue stress characteristics.

21. The microelectronic structure of claim 13, wherein one of the second dielectric layer or insulating layer is in tension, and the other of the second dielectric layer or the insulating layer is in compression.

22. A bonded structure comprising: the microelectronic structure of claim 13; and a second substrate having a front side and a back side, the front side including a nonconductive bonding layer and an exposed pad, wherein the nonconductive bonding layer on the front side of the second substrate is bonded to the nonconductive bonding layer on the back side of the first substrate, and wherein the exposed pad of the second substrate is bonded to the exposed end portion of the electrically conductive via.
