VIAS AND CONDUCTIVE ROUTING LAYERS IN SEMICONDUCTOR SUBSTRATES

TECHNICAL FIELD

[0001] The present disclosure is directed generally to vias and conductive routing layers in semiconductor substrates, and associated systems and devices.

BACKGROUND

[0002] Packaged semiconductor dies, including memory chips, microprocessor chips, and imager chips, typically include a semiconductor die mounted to a substrate and encased in a plastic protective covering. The die includes functional features, such as memory cells, processor circuits, imager devices, and interconnecting circuitry. The die also typically includes bond pads electrically coupled to the functional features. The bond pads are electrically connected to pins or other types of terminals that extend outside the protective covering for connecting to busses, circuits, and/or other microelectronic assemblies.

[0003] Market pressures continually drive manufacturers to reduce the size of semiconductor die packages and to increase the functional capacity of such packages. One approach for achieving these results is to stack multiple semiconductor dies in a single package. In such packages, the stacked dies can be electrically coupled together using conductive vias that extend through the entire thickness of the dies. The conductive vias are generally referred to as through silicon vias or TSV.

[0004] Conventional processes for forming TSVs include patterning a semiconductor substrate, etching the semiconductor substrate to create an aperture, and plating the aperture with a conductive material. Plating the aperture can include either pattern plating with a resist mask or blanket plating without a resist mask. Both plating techniques have certain drawbacks. For example, in addition to the other TSV processes, pattern plating includes forming a resist layer, patterning the resist layer, and removing the resist layer after plating, and/or other additional processing stages. On the other hand, even though blanket plating does not require as many steps as pattern plating, blanket plating creates a large amount of excess conductive material on the surface of semiconductor substrate. The excess conductive material must be

removed before subsequent processing stages, which takes time and wastes the conductive material. As a result, there remains a need for improved techniques for forming TSVs in semiconductor substrates.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Figures 1A-1D are schematic side cross-sectional views of a portion of a semiconductor die in accordance with embodiments of the technology.

[0006] Figures 2A-2H are schematic side cross-sectional views of a portion of a semiconductor substrate undergoing a process useful for forming several embodiments of the semiconductor die 100 of Figure 1A in accordance with embodiments of the technology.

[0007] Figures 3A-3D are schematic side cross-sectional views of a portion of a semiconductor substrate undergoing a process useful for forming several embodiments of the semiconductor die 100 of Figure 1A in accordance with additional embodiments of the technology.

DETAILED DESCRIPTION

[0008] Several embodiments of the present technology are described below with reference to processes for forming through vias and conductive routing layers in semiconductor substrates. Many details of certain embodiments are described below with reference to semiconductor dies. The term "semiconductor substrate" is used throughout to include a variety of articles of manufacture, including, for example, individual integrated circuit dies, imager dies, sensor dies, and/or dies having other semiconductor features. Several of the processes described below may be used to form through vias and conductive routing layers in an individual die, or in a plurality of dies, on a wafer or portion of a wafer. The wafer or wafer portion (e.g., wafer form) can include an unsingulated wafer or wafer portion, or a repopulated carrier wafer. The repopulated carrier wafer can include an adhesive material (e.g., a flexible adhesive) surrounded by a generally rigid frame having a perimeter shape comparable to that of an unsingulated wafer, and singulated elements (e.g., dies) surrounded by the adhesive.

[0009] Many specific details of certain embodiments are set forth in Figures 1A-3 and the following text to provide a thorough understanding of these embodiments. Several other embodiments can have configurations, components, and/or processes different than those

described in this disclosure. A person skilled in the relevant art, therefore, will appreciate that additional embodiments may be practiced without several of the details of the embodiments shown in Figures 1A-3.

[0010] Figure 1A is a schematic side cross-sectional view of a portion of a semiconductor die 100 processed in accordance with embodiments of the technology. As shown in Figure 1A, the semiconductor die 100 can include a substrate 102 and a routing structure 104. In the illustrated embodiment, the semiconductor die 100 also includes an optional first passivation material 106 on top of the routing structure 104 and an optional second passivation material 113 on the bottom of the substrate 102. The first and second passivation materials 106 and 113 can include silicon oxide, silicon nitride, and/or other suitable dielectric material. In other embodiments, the first and/or second passivation materials 106 and 113 may be omitted.

[0011] The substrate 102 has a first substrate surface 102a and a second substrate surface 102b. The substrate 102 can include doped or undoped silicon, TEOS, glass, ceramics, and/or other suitable material. The routing structure 104 can include a dielectric 105 with a first dielectric surface 105a and a second dielectric surface 105b. The first dielectric surface 105a is proximate the optional first passivation material 106, and the second dielectric surface 105b is proximate the first substrate surface 102a of the substrate 102.

[0012] The routing structure 104 can also include at least one electrically conductive trace 107 (two traces 107 are shown for illustration purposes) in the dielectric 105. The dielectric 105, for example, can include one or more depressions 109, and the traces 107 can include a first conductive material portion 112a that at least partially fills the depressions 109. In the illustrated embodiment, the individual depressions 109 have a generally rectangular cross-sectional area extending from the first dielectric surface 105a to the second dielectric surface 105b. In other embodiments, the depressions 109 can have oval, scalloped, and/or other cross-sectional areas that extend from the first dielectric surface 105a to an intermediate depth (not shown) in the dielectric 105. Even though only one routing structure 104 is shown in Figure 1A, in other embodiments, the semiconductor die 100 can also include two, three, or any other desired number of routing structures and conductive vias (not shown) electrically coupling at least some of the conductive routing structures.

[0013] The semiconductor die 100 can also include an integrated circuit 103 electrically coupled to at least one conductive through via 108 that extends through the dielectric 105 and

the substrate 102. The integrated circuit 103 can include a processor circuit, a RAM circuit, an ASIC circuit, and/or other suitable circuits. The through via 108 can include a second conductive material portion 112b at least partially filling an aperture 110 in the semiconductor die 100. In the illustrated embodiment, the aperture 110 extends from the first dielectric surface 105a of the dielectric 105 to the second substrate surface 102b of the substrate 102. In other embodiments, the aperture 110 can also extend from other locations in the dielectric 105 to the second substrate surface 102b of the substrate 102. In further embodiments, the aperture 110 can be entirely contained in the substrate 102.

[0014] As shown in Figure 1A, the through via 108 has a first end 108a open to the first dielectric surface 105a and a second end 108b proximate the second substrate surface 102b of the substrate 102. In certain embodiments, the first end 108a can form a first bond site 119 through an opening in the optional first passivation material 106, and the second end 108b can form a second bond site 121 through an opening in the optional second passivation material 113. The first and second bond sites 119 and 121 may be configured to interconnect with other dies, substrates, and/or external devices (not shown) with an interconnect component 114. In the illustrated embodiment, the interconnect component 114 includes a conductive pillar (e.g., a copper pillar) proximate to a wetting material 117 (e.g., a solder material). The interconnect component 114 connects the second end 108b of the semiconductor die 100 to a bond site 123 of another semiconductor die 101 (shown in phantom lines for clarity). The semiconductor die 101 may be structurally and/or functionally similar to or different from the semiconductor die 100. In other embodiments, the interconnect component 114 can also include a solder ball, a redistribution layer, a through silicon via stud, and/or other suitable interconnect devices components.

[0015] One feature of several embodiments of the semiconductor die 100 is that the first conductive material portion 112a of the traces 107 and the second conductive material portion 112b of the through via 108 (collectively referred to as the conductive material 112) can be formed simultaneously without intervening processing stages. As a result, the first and second conductive material portions 112a and 112b can be generally homogeneous. The homogeneity nature of the conductive material 112 is believed to enhance the reliability of the traces 107 and the through via 108, and therefore the semiconductor die 100, because the first and second conductive material portions 112a and 112b may be subsequently processed together (e.g., in an annealing stage). Several embodiments of the semiconductor die 100 can also have reduced

manufacturing costs when compared to conventional processes because certain processing stages may be eliminated, as described in more detail below with reference to Figures 2A-3D.

[0016] Even though the traces 107 and the through via 108 are isolated from each other in Figure 1A, Figure 1B shows another embodiment in which at least one of the traces 107 may be in contact with the through via 108. In other embodiments, the routing structure 104 may optionally include a conductive wire, trace, and/or another suitable interconnect structure 111 between at least one of the traces 107 and the through via 108, as shown in Figure 1C. In further embodiments, at least one of the traces 107 may be formed directly on top of the through via 108, as shown in Figure 1D. In any of these embodiments, the conductive material 112 of the traces 107, the through via 108, and the optional interconnect structure 111 may be formed in one single processing stage. As a result, the portions of the conductive material 112 in these features may be generally homogeneous and without any physical boundaries between one another (dash lines are shown in Figures 1B-1D for virtual demarcation purposes only).

[0017] Figures 2A-2H are schematic side cross-sectional views of a portion of a semiconductor substrate 200 undergoing a process useful for forming several embodiments of the semiconductor die 100 of Figure 1A in accordance with embodiments of the technology. As shown in Figure 2A, the process can include forming the dielectric 105 on top of the substrate 102. In certain embodiments, the dielectric 105 can be formed by depositing a dielectric material (e.g., silicon oxide) on the substrate 102 using chemical vapor deposition (CVD), atomic layer deposition (ALD), sputtering, and/or other suitable techniques. In other embodiments, the dielectric 105 can be formed by thermal oxidation of the substrate 102. Even though the dielectric 105 shown in Figure 2A is one single homogeneous layer, in certain embodiments, the semiconductor substrate 200 can also include multiple layers (not shown) of dielectric material with a physical boundary therebetween. In further embodiments, the semiconductor substrate 200 may also include a passivation material (e.g., silicon nitride), a barrier material (e.g., tantalum), and/or other suitable structures formed on and/or in the dielectric 105.

[0018] As shown in Figure 2B, a first photoresist material 202 is deposited on the dielectric 105 via spin coating or another suitable deposition technique. Subsequently, the first photoresist material 202 may be patterned to form first openings 204 in the first photoresist material 202. The first openings 204 can generally correspond to the pattern of the depressions 109 of Figures 1A-1C. The term "patterning" as used hereinafter generally refers to printing a

desired pattern on a photoresist material and subsequently removing certain portions of the photoresist material to form the desired pattern in the photoresist material using photolithography and/or other suitable techniques.

[0019] Figure 2C illustrates a first material removal stage of the process, in which the exposed portion of the dielectric 105 is at least partially removed to form the depressions 109 (illustrated as a first depression 109a and a second depression 109b) before the first photoresist material 202 is removed. Techniques for removing the exposed portion of the dielectric 105 can include wet etching, dry etching, reactive ion etching, and/or other suitable techniques. In one embodiment, the removal of the dielectric 105 can stop when the first substrate surface 102a of the substrate 102 is exposed. In other embodiments, the removal of the dielectric 105 can stop at an intermediate depth (not shown) before reaching the first substrate surface 102a of the substrate 102 by adjusting a removal duration (e.g., an etching period during a wet etch process), a removal intensity (e.g., a plasma concentration during a plasma etching process), and/or other suitable material removal parameters. In certain embodiments, the first and second depressions 109a and 109b may have a depth from about 0.3 microns to about 0.5 microns. In other embodiments, the first and second depressions 109a and 109b may have other suitable depths.

[0020] As shown in Figure 2D, after the depressions 109 are formed, the process can include at least partially covering the semiconductor substrate 200 with a second photoresist material 208. The process can also include subsequently patterning the second photoresist material 208 using photolithography and/or other suitable techniques to form a second opening 210 generally corresponding to the aperture 110 of the through via 108 (Figures 1A-1C). In certain embodiments, the second photoresist material 208 can have a composition that is generally similar to that of the first photoresist material 202. In other embodiments, the second photoresist material 208 can have compositions and/or characteristics that are different from that of the first photoresist material 202.

[0021] Figure 2E illustrates a second material removal stage, in which a portion of the dielectric 105 and the substrate 102 exposed in the second opening 210 is removed to form the aperture 110 using anisotropic etching, reactive ion etching, and/or other suitable techniques. In certain embodiments, the aperture 110 can have an aspect ratio from about 5:1 to about 20:1 and can extend into the substrate 102 at a depth of about 50 microns to about 200 microns. In other embodiments, the aperture 110 can have an aspect ratio of about 10:1 and can extend into the substrate material at a depth of about 100 microns. Subsequently, the process can include

removing the second photoresist material 208 from the semiconductor substrate 200. Optionally, the process can also include depositing a generally conformal insulating material (e.g., silicon oxide, not shown) in the aperture 110 before the second photoresist material 208 is removed. In other embodiments, the second material removal stage may include removing a portion of the dielectric 105 and the substrate 102 via laser drilling and/or other suitable drilling techniques without patterning the semiconductor substrate 200 with the second photoresist material 208, as discussed above with reference to Figure 2D.

[0022] As shown in Figure 2F, the process can include simultaneously filling the aperture 110 and the depressions 109 with a conductive material 212. The conductive material 212 includes a first portion 212a in the aperture 110, a second portion 212b in the depressions 109, and a third (or sacrificial) portion 212c extending beyond the first dielectric surface 105a of the dielectric 105. Suitable techniques for introducing the conductive material 212 into the aperture 110 and the depressions 109 can include pulsed chemical vapor deposition (pCVD), ionic physical vapor deposition (iPVD), atomic layer deposition (ALD), electro-grafting, bottom-up ECD plating, electroless plating, and/or other suitable techniques. The conductive material 212 can include copper, aluminum, tungsten, gold and/or alloys of the foregoing constituents. In particular embodiments, the conductive material 212 includes electrolytic copper introduced into the aperture 110 and/or the depressions 109 lined with a barrier material (e.g., tantalum). The electrolytic copper has an enhanced purity when compared to electrolessly disposed materials, and when compared to solder. For example, the conductive material can be at least 90% copper and in some cases, 99% copper.

[0023] As shown in Figure 2G, the third portion 212c of the conductive material 212 can be subsequently removed such that the first and second portions 212a and 212b of the conductive material 212 are generally flush with the first dielectric surface 105a. Techniques for removing the third portion 212c of the conductive material 212 can include chemical-mechanical polishing, electrochemical-mechanical polishing, and/or other suitable techniques.

[0024] The process can also include subsequently processing the semiconductor substrate 200 to form additional features in and/or on the semiconductor substrate 200. For example, as shown in Figure 2H, a portion of the substrate 102 can be removed from the second substrate surface 102b using a mechanical or chemical-mechanical technique to expose the second end 108b of the through via 108. An interconnect component 114 (e.g., a conductive pillar, a solder ball, a solder bump, a redistribution layer, a through silicon via stud, and/or other suitable

interconnect devices) can then be attached to the second end 108b for interconnecting with an external component (not shown). The optional first and/or second passivation materials 106 and 113 can be deposited onto the dielectric 105 for insulating the traces 107 and the through via 108. In other examples, additional dielectric materials and/or conductive traces may be formed on top of the routing structure 104 and/or the optional first and second passivation materials 106 and 113.

[0025] Several embodiments of the process can be more efficient than conventional techniques by reducing several processing stages. Conventional techniques for forming through vias and traces in a semiconductor substrate typically include two conductive material deposition stages. In a first deposition stage, the through vias are initially formed, and in a second deposition stage, the traces are formed. By simultaneously depositing the conductive material 212 into both the depressions 109 and the aperture 110, only one deposition stage is required. As a result, the second deposition stage and any associated processing stages (e.g., polishing, cleaning, etc.) may be eliminated, thus improving the efficiency and cost-effectiveness of the fabrication process.

[0026] Several embodiments of the process can also reduce the risk of polishing defects (e.g., dishing) in the through via 108 and/or the traces 107. Typically, the exposed surface of the conductive material 212 in the through via 108 only occupies a small portion of the total surface area of the semiconductor substrate 200. If the traces 107 were not present, and the semiconductor substrate 200 was polished with only the conductive material 212 in the through via 108, the polishing pressure on the semiconductor substrate 200 would tend to be non-uniform over the entire surface area of the substrate. Such non-uniformity is believed to result in dishing, chipping, and/or other polishing defects. In contrast, in several embodiments of the process, the conductive material 212 occupies more of the total surface area of the semiconductor substrate 200 because the conductive material 212 is in both the through via 108 and in the traces 107. Without being bound by theory, it is believed that the increased surface area of the conductive material 212 can reduce the non-uniformity of the polishing pressure, and thus reducing the risk of polishing defects.

[0027] Even though the foregoing process discussed with reference to Figures 2A-2H includes forming the depressions 109 before forming the aperture 110, Figures 3A-3D describe a process that includes forming the aperture 110 before forming the depressions 109. As shown in Figure 3A, the process includes depositing a first photoresist material 302 onto the dielectric

105. The process can also include patterning the first photoresist material 302 to form a first opening 304 generally corresponding to the aperture 110 (Figures 1A-1C).

[0028] As shown in Figure 3B, the process can include a first material removal stage, in which a portion of the dielectric 105 and the substrate 102 exposed in the first opening 304 is removed to form the aperture 110 using any of the suitable techniques discussed above. Subsequently, the process can include removing the first photoresist material 302 from the semiconductor substrate 200.

[0029] The process can also include depositing a layer of insulating material 306 in the aperture 110 and on the first dielectric surface 105a of the dielectric 105. The insulating material 306 can include silicon oxide, silicon nitride, and/or other suitable material. Suitable techniques for depositing the insulating material 306 can include, but are not limited to, chemical vapor deposition (CVD), physical vapor deposition (PVD), atomic layer deposition (ALD), thermo oxidation, and/or other suitable techniques.

[0030] As shown in Figure 3C, the process includes depositing a second photoresist material 308 onto the insulating material 306. The process can also include patterning the second photoresist material 308 to form second openings 310 generally corresponding to the depressions 109 (Figures 1A-1C).

[0031] As shown in Figure 3D, the process can include a second material removal stage, in which a portion of the insulating material 306 and the dielectric 105 generally corresponding to the second openings 310 is removed to form the depressions 109. Subsequently, the process can include removing the second photoresist material 308 from the semiconductor substrate 200. Then the process may include processing stages as discussed above with reference to Figures 2F-2H to form the semiconductor die 100 of Figures 1A-1C.

[0032] Several embodiments of the process can be more efficient in forming the insulating material 306 in the aperture 110 than conventional techniques. In accordance with conventional techniques, the depressions 109 may need to be shielded from the insulating material 306 with a fill material (if the depressions 109 are formed before forming the aperture 110) or a portion of the insulating material 306 external to the aperture 110 has to be removed via costly polishing (if the depressions 109 are formed after forming the aperture 110). In contrast, several embodiments of the process discussed above may eliminate such processing stages because the

part of the insulating material 306 corresponding to the depressions 109 is simply removed during the second material removal stage.

[0033] The processing stages described above with reference to Figures 2A-3D are for illustration purposes. A person of ordinary skill in the art will recognize that certain processing stages are omitted for clarity. For example, in certain embodiments, before filling the depressions 109 and the aperture 110 with the conductive material 212, a barrier material, a seed material, and/or other suitable structures may be formed in the aperture 110 and/or the depressions 109. A person of ordinary skill in the art will also recognize that the foregoing processing stages may be modified for forming several embodiments of the semiconductor die 100' and 100" of Figures 1B and 1C, respectively. For example, the depressions 109 and the aperture 110 may be patterned as a single contiguous depression, as shown in Figure 1B, or the interconnect structure 111 may be patterned with the depressions 109 and/or the aperture 110, as shown in Figure 1C. In any of the foregoing embodiments, the process can further include at least one stage of cleaning, drying, cooling, annealing, and/or other suitable stages.

[0034] From the foregoing, it will be appreciated that specific embodiments of the technology have been described herein for purposes of illustration, but that various modifications may be made without deviating from the disclosure. For example, even though several embodiments of the processes are described above with reference to forming a semiconductor die, certain embodiments of the processes may also be applied to a semiconductor wafer in which a plurality of semiconductor dies may be formed. Many of the elements of one embodiment may be combined with other embodiments in addition to or in lieu of the elements of the other embodiments. For example, even though the depressions 109 and the aperture 110 of Figures 1A-3D are shown as formed in two material removal stages, in certain embodiments, these features may be patterned and formed in one single processing stage using phase shift masks and/or other suitable techniques. Accordingly, the disclosure is not limited except as by the appended claims.

Claims

1. A device, comprising:

a semiconductor substrate having a first substrate surface and a second substrate surface;

a dielectric on the semiconductor substrate, the dielectric having a first dielectric surface and a second dielectric surface, wherein the second dielectric surface is in direct contact with the first substrate surface;

a depression in the dielectric;

an aperture through the dielectric and at least a portion of the semiconductor substrate;

a conductive material having a first portion in the depression and a second portion in the aperture; and

a conductive interconnect structure positioned within the dielectric and electrically coupled to the conductive material in the aperture, wherein the conductive interconnect structure is laterally positioned between the conductive material and a trace positioned within the dielectric.

2. The device of claim 1 wherein:

the depression extends between the first dielectric surface and the second dielectric surface;

the aperture extends from the first dielectric surface to the second substrate surface; and

the first and second portions of the conductive material are generally homogeneous.

3. The device of claim 1, further comprising:

a solder ball attached to an exposed portion of the conductive material at the second end of the aperture.

4. The device of claim 3, wherein the exposed portion has a polished conductive material.

5. The device of claim 1, wherein the aperture has a depth of at least 50 microns from the first dielectric surface and an aspect ratio of at least 5:1.

6. The device of claim 1, wherein the depression has a depth of about 0.3 to about 0.5 microns from the first dielectric surface.

7. The device of claim 1, wherein the first and second portions of the conductive material include copper.

8. The device of claim 1, wherein the first and second portions of the conductive material are generally contiguous.

9. The device of claim 1, wherein the first and second portions of the conductive material do not include a physical boundary between each other.

10. The device of claim 1, wherein the first and second portions of the conductive material are formed in one single processing stage such that a sacrificial portion of the conductive material extends between the first and second portions.

11. A semiconductor device, comprising:

a substrate having a first substrate surface and a second substrate surface;

a dielectric on the substrate, the dielectric having a first dielectric surface and a second dielectric surface, wherein the second dielectric surface is in contact with the first substrate surface;

a depression formed in the dielectric;

an aperture through the dielectric and at least a portion of the substrate;

a conductive material having a first portion in the depression and a second portion in the aperture; and

a conductive interconnect structure in the dielectric and electrically coupled to the conductive material, wherein the conductive interconnect structure is laterally positioned between the conductive material and a trace positioned within the dielectric.

12. The semiconductor device of claim 11, wherein the aperture has an open end at the first dielectric surface and a closed end in the substrate toward the second substrate surface, and wherein a first cross-sectional area of the aperture is generally the same as a second cross-sectional area of the aperture at the closed end.

13. The semiconductor device of claim 11, further comprising:

an insulation material positioned in the aperture and on the first dielectric surface of the dielectric.

14. The semiconductor device of claim 13, wherein the insulation material has a first insulation portion in the aperture and a second insulation portion on the first dielectric surface of the dielectric.

15. The semiconductor device of claim 11, further comprising:

a solder ball attached to an exposed portion of the conductive material.

16. A semiconductor wafer, comprising:

a substrate having a first substrate surface and a second substrate surface;

a dielectric on the substrate, the dielectric having a first dielectric surface and a second dielectric surface, wherein the second dielectric surface is in contact with the first substrate surface;

a plurality of depressions formed in the dielectric;

at least one aperture through the dielectric and at least a portion of the substrate;

a conductive material having a first portion in the plurality of depressions and a second portion in the aperture; and

a conductive interconnect structure in the dielectric and electrically coupled to the conductive material, wherein the conductive interconnect structure is

laterally positioned between the conductive material and a trace positioned within the dielectric.

17. The semiconductor wafer of claim 16, wherein the aperture has an open end at the first dielectric surface and a closed end in the substrate toward the second substrate surface, and wherein a first cross-sectional area of the aperture is generally the same as a second cross-sectional area of the aperture at the closed end.

18. The semiconductor wafer of claim 16, further comprising:

an insulation material positioned in the aperture and on the first dielectric surface of the dielectric, wherein the insulation material has a first insulation portion in the aperture and a second insulation portion on the first dielectric surface of the dielectric.

19. The semiconductor wafer of claim 16, further comprising:

a solder ball attached to an exposed portion of the conductive material, wherein the exposed portion has a surface with a polished conductive material.

20. The semiconductor wafer of claim 16, wherein the aperture has a depth of at least 50 microns from the first dielectric surface and an aspect ratio of at least 5:1, and wherein the depression has a depth of about 0.3 to about 0.5 microns from the first dielectric surface.