

DIRECT BOND METHOD PROVIDING THERMAL EXPANSION MATCHED DEVICES

BACKGROUND

[0001] The present disclosure relates to a direct bond method and to a direct bond method that provides for thermal expansion matched devices for true heterogeneous three-dimensional integration.

[0002] Many currently used infrared sensor chip assemblies include silicon readout integrated circuits (ROIC) that are hybridized to mercury cadmium tellurium (HgCdTe) detector arrays using indium (In) bumps. Problems with such assemblies exist, however, in that these indium bumps tend to fail as a result of their inability to survive the large number of thermal cycles required for the assembly processes due to the coefficient of thermal expansion (CTE) mismatch between silicon (Si) and the HgCdTe.

[0003] While previous attempts to address these problems have been attempted, none are completely useful or satisfactory. For example, for indium bump (IB) focal plane arrays (FPAs), the approach has been to attempt to CTE match the ROIC to a detector by adhesively bonding titanium (Ti) and silicon (Si) shims to the back of a sensor chip assembly (SCA) after dicing and hybridization. While this approach can be effective, it is an expensive die-level process and is performed manually by skilled labor.

[0004] As another example, for heterogeneous three-dimensional (3D) integration, approaches include epitaxial growth of III-V semiconductor materials, such as gallium nitride (GaN), on a silicon (Si) substrate using buffer layers to provide the lattice match, or ultrasonically bonding a bonded completed III-V die to a silicon (Si) circuit. In both of these cases, III-V layers can tend to cause degraded performance due to stress associated with CTE mismatches between the III-V devices and silicon (Si) substrates.

SUMMARY

[0005] According to one aspect, there is provided a method of transferring an integrated circuit (IC) onto an alternative substrate at a wafer level to enable coefficient of thermal expansion (CTE) matching for a circuit layer to a different material. The method is executable relative to a wafer with a circuit layer having a first major surface and a second major surface opposite the first major surface, and a substrate affixed to the first major surface. The method includes temporarily bonding a handle to the second major surface, removing a substantial portion of the substrate to expose the first major surface and bonding a second substrate to the first major surface with deposited bonding material to hybridize the circuit layer; removing the handle from the second major surface; and connecting the second

major surface to an additional substrate, which is thermally matched to the circuit layer hybridized with the second substrate.

[0006] According to another aspect, there is provided a method of transferring an integrated circuit (IC) onto an alternative substrate at a wafer level to enable coefficient of thermal expansion (CTE) matching. The method is executable relative to a complementary-metal-oxide-semiconductor (CMOS) wafer with a circuit layer, a first major surface, a second major surface opposite the first major surface, and a substrate affixed to the first major surface. The method includes temporarily bonding a handle to the second major surface, removing a substantial portion of the substrate to expose the first major surface through a thin layer of substrate remainder and bonding a Sapphire substrate to the first major surface and the thin layer of substrate remainder with a deposited and polished bonding oxide to hybridize the circuit layer; removing the handle from the second major surface; and connecting the second major surface to an additional substrate, which is thermally matched to the circuit layer hybridized with the second substrate.

[0007] Disclosed herein is a wafer level integrated circuit (IC) transfer enabling structure. The structure includes a circuit layer having a first major surface and a second major surface opposite the first major surface, a substrate remainder, which is substantially thinner than the circuit layer, affixed to the first major surface, a handle temporarily bonded to the second major surface, and a Sapphire substrate bonded to the first major surface and the substrate remainder with a deposited and polished bonding oxide.

[0008] Additional features and advantages are realized through embodiments of the present invention. Other embodiments and aspects of the invention are described in detail herein and are considered a part of the claimed invention.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0009] For a more complete understanding of this disclosure, reference is now made to the following brief description, taken in connection with the accompanying drawings and detailed description, wherein like reference numerals represent like parts:

[0010] FIG. 1 is a schematic illustration of a wafer manufacturing foundry and a processing plant in accordance with embodiments;

[0011] FIG. 2 is a side view of a wafer produced in the foundry of FIG. 1 in accordance with embodiments;

[0012] FIG. 3 is a side view of a handle that is temporarily bonded to the wafer of FIG. 2;

[0013] FIG. 4A is a side view of the handle and the wafer of FIG. 3 following removal of substrate material from the wafer;

[0014] FIG. 4B is an enlarged side view of the encircled portion of the circuit layer following the removal of the substantial portion of the substrate material in accordance with embodiments;

[0015] FIG. 5A is a side view of bonding material applied to the substrate-lacking wafer of FIG. 4A;

[0016] FIG. 5B is a schematic illustration of the deposition and then polishing of the bonding material of FIG. 5A in accordance with embodiments;

[0017] FIG. 6 is a side view of a new substrate bonded to the formerly substrate-lacking wafer by the bonding material of FIGS. 5A and 5B;

[0018] FIG. 7 is a side view of a wafer bonded to the new substrate of FIG. 6 with the temporary handle of FIG. 3 having been removed; and

[0019] FIG. 8 is a side view of an oxide bonded, three-dimensional (3D) integrated circuit (IC) using mixed semiconductor materials in accordance with embodiments.

DETAILED DESCRIPTION

[0020] As will be discussed below, a coefficient of thermal expansion (CTE) matched readout integrated circuit (ROIC) is produced at a wafer level before hybridization to thereby increase yield and decrease costs. The method of production can also be used to produce oxide bonded three-dimensional (3D) ICs using mixed semiconductor materials as in true heterogeneous devices.

[0021] With reference to FIG. 1, a wafer manufacturing foundry 10 is provided remotely from a processing plant 20. The wafer manufacturing foundry 10 is configured and equipped to manufacture standard complementary-metal-oxide-semiconductor (CMOS) wafers 11, for example, which can be shipped to the processing plant 20 for further processing as will be described below. While the wafer manufacturing foundry 10 is illustrated and described herein as being remote and separate from the processing plant 20, it is to be understood that this is not necessary and that the two features can be provided in a single element. Even then, however, the manufacturing processes used to produce the CMOS wafers 11 are separate and distinct from the further processing that is described below.

[0022] With reference to FIGS. 2-7, a method of transferring an integrated circuit (IC) onto an alternative substrate at a wafer level to enable CTE matching is provided. While it is understood that the method is executable in the processing plant 20 relative to various types of wafers including, for example, the CMOS wafers 11 produced in the wafer manufacturing foundry 10 (each shown in FIG. 1), the following description will relate only to the cases

where the method is executed in the processing plant 20 relative to the CMOS wafers 11 produced in the wafer manufacturing foundry 10. This is done for clarity and brevity and should not be considered as limiting the following description or claims in any way.

[0023] As shown in FIG. 2, each one of the CMOS wafers 11 includes a circuit layer 12 and a substrate 13. The circuit layer 12 is substantially planarized and may include various circuit elements, traces and CMOS devices. The circuit layer 12 may be approximately 10 μm thick and has a body 120, a first major surface 121 on a first side of the body 120 and a second major surface 122 on a second side of the body 120 opposite the first side of the body 120. The substrate 13 is affixed or bonded to the first major surface 121.

[0024] As shown in FIG. 3, a wafer-level handle (or simply handle) 14 is temporarily bonded to the second major surface 122 of the circuit layer 12. The handle 14 may be formed of any suitable, somewhat rigid material including, but not limited to, metallic materials, ceramic materials and organic or inorganic dielectric, semiconductor or conductive materials. The handle 14 can be flat and have a uniform thickness and may be, but is not required to be, planarized. In any case, the handle 14 should generally conform to the topography of the second major surface 122. The temporary bond between the handle 14 and the second major surface 122 may be provided by way of adhesive bonding using a thermoplastic adhesive.

[0025] As shown in FIG. 4A, all or a substantial portion (e.g., ~90% or a majority) of the substrate 13 is removed. The removal of the substantial portion of the substrate 13 can be accomplished or conducted by way of etching, grinding and polishing or, more particularly, by way of a grinding of the bulk of the material of the substrate 13 stopping at a depth of approximately 10X the grit size from the desired final thickness and then polishing the last bits of the material of the substrate 13 away from the circuit layer 12. In any case, the removal of the substantial portion of the substrate 13 serves to completely expose the first major surface 121 or, as shown in FIG. 4B, to nearly completely expose the first major surface 121 through a thin layer of substrate remainder 130. In accordance with embodiments, the thin layer of the substrate remainder 130 (if it exists) is substantially thinner than the circuit layer 12 even where the circuit layer 12 is approximately ~10 μm thick. As an example, for a modern complementary-metal-oxide-semiconductor (CMOS) process, the wafer would be thinned so that the thickness of the substrate remainder would be 10 μm or less.

[0026] Although FIGS. 4A and 4B illustrate that the substrate 13 can be completely removed or that a substantial portion of the substrate 13 can be removed with only a thin

layer of substrate remainder 130 remaining, the following description will relate to the former case for purposes of clarity and brevity.

[0027] As shown in FIG. 5A, an adhesive 15 is applied to the first major surface 121 of the circuit layer 12 that is now exposed as a result of the removal of the substrate 13. In accordance with embodiments and, as shown in FIG. 5B, the adhesive 15 may include bonding oxide that is deposited (e.g., by physical vapor deposition or PVD) onto the first major surface 121 up to a first thickness T1 and then polished (e.g., by chemical mechanical polishing or CMP) down to a second thickness T2. The first thickness T1 may be approximately 2-15 nm and the second thickness T2 may be approximately 0.3-0.5 nm.

[0028] As shown in FIG. 6, a wafer-level second substrate (or simply new or second substrate) 16 is bonded to the first major surface 121 of the circuit layer 12 (and any thin layer of substrate remainder 130 that remains on the first major surface 121) using low-temperature oxide bonding (i.e., with the deposited and polished bonding oxide or adhesive 15). The second substrate 16 may be approximately 725 μm thick and may be provided as or with a plasma activated oxide surface. The second substrate 16 material can be an aluminum oxide, Sapphire or ceramic. In the particular and exemplary case of the second substrate 16 being formed of Sapphire and/or other similar materials, the second substrate 16 effectively functions as a thermal matching substrate.

[0029] As used herein, a thermal matching substrate may be any substrate that, when bonded to the circuit layer 12, alters the rate of thermal expansion of the circuit layer 12 in a desirable manner. In other words, the thermal matching substrate may include any material suitable for bonding to the circuit layer 12 and having a CTE that is different than the CTE of the circuit layer 12. In certain embodiments, the thermal matching substrate can be a substrate that forms a composite-semiconductor structure having a desired rate of thermal expansion. This desired rate of thermal expansion may be substantially equal to the rate of thermal expansion of a substrate to which the circuit layer 12 is to be hybridized.

[0030] The second substrate 16, acting as a thermal matching substrate, may have a CTE that is greater than the CTE of the circuit layer 12. As a result, when the second substrate 16 is bonded to the circuit layer 12 (and a balancing substrate that may also be present), the second substrate 16 causes the circuit layer 12 to expand and contract at a greater rate in response to temperature changes. Alternatively, the second substrate 16 may have a CTE that is smaller than the CTE of the circuit layer 12. As a result, when the second substrate 16 is bonded to the circuit layer 12 (and the balancing substrate that may also be present), the second substrate 16 causes the circuit layer 12 to expand and contract at a slower

rate in response to temperature changes. Here the, balancing substrate (not shown) may be any substrate that, when bonded to the second substrate 16, reduces or eliminates warping of the resulting composite-semiconductor structure of the second substrate 16 and the circuit layer 12 without substantially impacting the effective CTE of the composite-semiconductor structure.

[0031] In any case, FIG. 6 illustrates a wafer level integrated circuit (IC) transfer enabling structure 60. The structure 60 includes the circuit layer 12 having the first major surface 121 and the second major surface 122 opposite the first major surface 121, a potentially very thin or non-existing substrate remainder 130 (not shown in FIG. 6) that is substantially thinner than the circuit layer 12 affixed to the first major surface 121, the handle 14 being temporarily bonded to the second major surface 122 and a second (e.g., Sapphire) substrate 16. The second substrate 16 is bonded to the first major surface 121 (and any thin layer of substrate remainder 130) with the adhesive 15.

[0032] With reference to FIG. 7, once the second substrate 16 is bonded to the first major surface 121 of the circuit layer 12, the handle 14 is removed leaving the second major surface 122 exposed and the circuit layer 12 permanently bonded to the second substrate 16.

[0033] In accordance with further embodiments and, with reference to FIG. 8, the circuit layer 12 to which the second substrate 16 is permanently bonded may form a hybridization ready structure 80 that is ready to be hybridized to a detector array. As such, as shown in FIG. 8, a device 801 is formed by hybridizing the circuit layer 12 (with the second substrate 16) to a thermally matched second substrate 802 using interconnects 803 that are deposited on the second major surface 122 of the circuit layer 12 and on complementary surface 804 of the second substrate 802. The second substrate 802 may be provided, for example, as a detector array and as such includes an array of photo-electric elements therein. At least one or more of the interconnects 803 may be formed of indium (as in the case of indium bumps) and/or other similar materials (e.g., tin, lead, bismuth alloy or any other suitable conductive material).

[0034] The corresponding structures, materials, acts, and equivalents of all means or step plus function elements in the claims below are intended to include any structure, material, or act for performing the function in combination with other claimed elements as specifically claimed. The description of the present invention has been presented for purposes of illustration and description, but is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the invention. The

embodiments were chosen and described in order to best explain the principles of the invention and the practical application, and to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated.

[0035] For comparison, US Patent No. 8,154,099 describes a CTE matching method where the CTE matching material is atomically bonded between two layers of semiconductor in order to adjust a composite material CTE to match another layer. In this case, the semiconductor layers are relatively thin and the CTE matching material is insufficiently stiff whereby a three layer structure is used to prevent the resulting structure from warping during temperature excursions. The description provided above, however, relates to cases in which the semiconductor layer (i.e., the circuit layer 12) is relatively thin (e.g., approximately 10 μm) and the CTE matching substrate (i.e., the second substrate 16) is relatively thick (e.g., approximately 1500 μm). This significant thickness difference allows the CTE matching substrate to be highly resistant to warping so that warping effects in the resulting composite structure are effectively insignificant.

[0036] While the preferred embodiments to the invention have been described, it will be understood that those skilled in the art, both now and in the future, may make various improvements and enhancements which fall within the scope of the claims which follow. These claims should be construed to maintain the proper protection for the invention first described.

CLAIMS

1. A method of transferring an integrated circuit (IC) onto an alternative substrate at a wafer level to enable coefficient of thermal expansion (CTE) matching for a circuit layer to a different material,
the method being executable relative to a wafer with a circuit layer having a first major surface and a second major surface opposite the first major surface, and a substrate affixed to the first major surface,
the method comprising:
temporarily bonding a handle to the second major surface;
removing a substantial portion of the substrate to expose the first major surface;
bonding a second substrate to the first major surface with deposited bonding material to hybridize the circuit layer;
removing the handle from the second major surface; and
connecting the second major surface to an additional substrate, which is thermally matched to the circuit layer hybridized with the second substrate.
2. The method according to claim 1, wherein the wafer comprises a complementary-metal-oxide-semiconductor (CMOS) wafer.
3. The method according to claim 1, wherein temporarily bonding a handle to the second major surface comprises applying thermoplastic adhesive.
4. The method according to claim 1, wherein the removing of the substantial portion of the substrate comprises at least one or more of grinding and polishing.
5. The method according to claim 1, wherein the removing of the substantial portion of the substrate leaves a remainder of the substrate that is thinner than the circuit layer.
6. The method according to claim 1, wherein the circuit layer is approximately 10 μm thick and the removing of the substantial portion of the substrate leaves a remainder of the substrate that is thinner than the circuit layer.

7. The method according to claim 1, wherein the deposited bonding material comprises bonding oxide.
8. The method according to claim 1, wherein bonding a second substrate to the first major surface comprises:
 - depositing the bonding material to the first major surface with a thickness of approximately 2-15 nm; and
 - polishing the bonding material down to a thickness of approximately 0.3-0.5 nm.
9. The method according to claim 1, wherein the second substrate comprises a plasma activated surface or aluminum oxide.
10. The method according to claim 1, wherein the circuit layer is approximately 10 μm thick and the second substrate is approximately 1500 μm thick.
11. A method of transferring an integrated circuit (IC) onto an alternative substrate at a wafer level to enable coefficient of thermal expansion (CTE) matching,
 - the method being executable relative to a complementary-metal-oxide-semiconductor (CMOS) wafer with a circuit layer having a first major surface and a second major surface opposite the first major surface, and a substrate affixed to the first major surface;
 - temporarily bonding a handle to the second major surface;
 - removing a substantial portion of the substrate to expose the first major surface through a thin layer of substrate remainder;
 - bonding a Sapphire substrate to the first major surface and the thin layer of substrate remainder with a deposited and polished bonding oxide to hybridize the circuit layer;
 - removing the handle from the second major surface; and
 - connecting the second major surface to an additional substrate, which is thermally matched to the circuit layer hybridized with the second substrate.
12. The method according to claim 11, wherein:
 - temporarily bonding a handle to the second major surface comprises applying thermoplastic adhesive.

13. The method according to claim 11, wherein the removing of the substantial portion of the substrate comprises at least one or more of grinding and polishing the substrate down to the substrate remainder.

14. The method according to claim 11, wherein the circuit layer is approximately 10 μm thick and the substrate remainder is thinner than the circuit layer.

15. The method according to claim 11, wherein the circuit layer is approximately 10 μm thick and the Sapphire substrate is approximately 1500 μm thick.

16. The method according to claim 1, wherein the additional substrate comprises a detector array.

17. The method according to claim 16, wherein:
the detector array comprises photo-electric elements and an additional surface which is complementary to the second major surface, and
the connecting comprises depositing interconnects on the second major surface and on the additional surface.

18. The method according to claim 11, wherein the additional substrate comprises a detector array.

19. The method according to claim 18, wherein:
the detector array comprises photo-electric elements and an additional surface which is complementary to the second major surface, and
the connecting comprises depositing interconnects on the second major surface and on the additional surface.