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DUAL-SIDED ROUTING IN 3D SEMICONDUCTOR SYSTEM-IN-PACKAGE STRUCTURE AND METHODS OF FORMING THE SAME

Abstract

A semiconductor package is fabricated by attaching a first component to a second component. The first component is assembled by forming a first redistribution structure over a substrate. A through via is then formed over the first redistribution structure, and a die is attached to the first redistribution structure active-side down. The second component includes a second redistribution structure, which is then attached to the through via. A molding compound is deposited between the first redistribution structure and the second redistribution structure and further around the sides of the second component.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation of U.S. patent application Ser. No. 18/447,769, filed Aug. 10, 2023, entitled “Dual-sided Routing in 3D Semiconductor System-In-Package Structure and Methods of Forming the Same,” which is a continuation of U.S. patent application Ser. No. 17/690,206, filed Mar. 9, 2022, entitled “Dual-Sided Routing in 3D SiP Structure,” now U.S. Pat. No. 11,824,007, issued on Nov. 21, 2023, which is a divisional of U.S. patent application Ser. No. 16/811,465, filed on Mar. 6, 2020, entitled “Dual-Sided Routing in 3D SiP Structure,” now U.S. Pat. No. 11,322,447, issued on May 3, 2022, which application claims the benefit of U.S. Provisional Application No. 62/888,277, filed on Aug. 16, 2019, entitled “Innovative Ultra-thin Dual-side Routing 3D SiP Structure,” which applications are hereby incorporated herein by reference in their entirety.

BACKGROUND

[0002] The semiconductor industry has experienced rapid growth due to ongoing improvements in the integration density of a variety of electronic components (e.g., transistors, diodes, resistors, capacitors, etc.). For the most part, improvement in integration density has resulted from iterative reduction of minimum feature size, which allows more components to be integrated into a given area. As the demand for shrinking electronic devices has grown, a need for smaller and more creative packaging techniques of semiconductor dies has emerged. An example of such packaging systems is Package-on-Package (PoP) technology. In a PoP device, a top semiconductor package is stacked on top of a bottom semiconductor package to provide a high level of integration and component density. PoP technology generally enables production of semiconductor devices with enhanced functionalities and small footprints on a printed circuit board (PCB).

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] Aspects of the present disclosure are best understood from the following detailed description when read with the accompanying figures. It is noted that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

[0004] FIG. 1 illustrates a cross-sectional view of an integrated circuit die, in accordance with some embodiments.

[0005] FIGS. 2A through 2G illustrate cross-sectional views of intermediate steps during a process for forming package components, in accordance with some embodiments.

[0006] FIGS. 3A through 3H illustrate cross-sectional views of intermediate steps during a process

for forming package components, in accordance with some embodiments.

[0007] FIGS. 4A through 4H illustrate cross-sectional views of intermediate steps during a process for forming package components, in accordance with some embodiments.

[0008] FIGS. 5A through 5H illustrate cross-sectional views of intermediate steps during a process for forming package components, in accordance with some embodiments.

[0009] FIGS. 6A through 6H illustrate cross-sectional views of intermediate steps during a process for forming package components, in accordance with some embodiments.

DETAILED DESCRIPTION

[0010] The following disclosure provides many different embodiments, or examples, for implementing different features of the invention. Specific examples of components and arrangements are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to be limiting. For example, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed between the first and second features, such that the first and second features may not be in direct contact. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed.

[0011] Further, spatially relative terms, such as “beneath,” “below,” “lower,” “above,” “upper” and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. The spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. The apparatus may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein may likewise be interpreted accordingly.

[0012] In accordance with some embodiments, one or more integrated circuit dies and other devices are attached to dual-sided redistribution structures and embedded in an encapsulant to form a semiconductor system-in-package (SiP) structure. One of the redistribution structures may have a fan-out design while the other may be formed in a carrier-type substrate. The placement of the integrated circuit dies and layouts of the redistribution structures provide versatility in the overall package. Further, the design of the package and redistribution structures, as well as the methodology, facilitate a thinner SiP structure with greater strength and reduced overall package warpage.

[0013] FIG. 1 illustrates a cross-sectional view of an integrated circuit die 50, in accordance with some embodiments. The integrated circuit die 50 will be packaged in subsequent processing to form an integrated circuit package. The integrated circuit die 50 may be a logic die (e.g., central processing unit (CPU), graphics processing unit (GPU), system-on-a-chip (SoC), application processor (AP), microcontroller, etc.), a memory die (e.g., dynamic random access memory (DRAM) die, static random access memory (SRAM) die, etc.), a power management die (e.g., power management integrated circuit (PMIC) die), a radio frequency (RF) die, a sensor die, a micro-electro-mechanical-system (MEMS) die, a signal processing die (e.g., digital signal processing (DSP) die), a front-end die (e.g., analog front-end (AFE) dies), the like, or combinations thereof.

[0014] The integrated circuit die 50 may be formed in a wafer, which may include different device regions that are singulated in subsequent steps to form a plurality of integrated circuit dies. The integrated circuit die 50 may be processed according to applicable manufacturing processes to form integrated circuits. For example, the integrated circuit die 50 includes a semiconductor substrate 52, such as silicon, doped or undoped, or an active layer of a semiconductor-on-insulator (SOI) substrate. The semiconductor substrate 52 may include other semiconductor materials, such as

germanium; a compound semiconductor including silicon carbide, gallium arsenic, gallium phosphide, indium phosphide, indium arsenide, and/or indium antimonide; an alloy semiconductor including SiGe, GaAsP, AlInAs, AlGaAs, GaInAs, GaInP, and/or GaInAsP; or combinations thereof. Other substrates, such as multi-layered or gradient substrates, may also be used. The semiconductor substrate **52** has an active surface (e.g., the surface facing upwards in FIG. **1**), sometimes called a front side, and an inactive surface (e.g., the surface facing downwards in FIG. **1**), sometimes called a back side.

[0015] Devices (one being shown in FIG. **1**) **54** may be formed at the front surface of the semiconductor substrate **52**. The devices **54** may be active devices (e.g., transistors, diodes, etc.), capacitors, resistors, etc. An inter-layer dielectric (ILD) **56** is over the front surface of the semiconductor substrate **52**. The ILD **56** surrounds and may cover the devices **54**. The ILD **56** may include one or more dielectric layers formed of materials such as Phospho-Silicate Glass (PSG), Boro-Silicate Glass (BSG), Boron-Doped Phospho-Silicate Glass (BPSG), undoped Silicate Glass (USG), or the like.

[0016] Conductive plugs **58** extend through the ILD **56** to electrically and physically couple the devices **54**. For example, when the devices **54** are transistors, the conductive plugs **58** may couple the gates and source/drain regions of the transistors. The conductive plugs **58** may be formed of tungsten, cobalt, nickel, copper, silver, gold, aluminum, the like, or combinations thereof. An interconnect structure **60** is over the ILD **56** and conductive plugs **58**. The interconnect structure **60** interconnects the devices **54** to form an integrated circuit. The interconnect structure **60** may be formed by, for example, metallization patterns in dielectric layers on the ILD **56**. The metallization patterns include metal lines and vias formed in one or more low-k dielectric layers. The metallization patterns of the interconnect structure **60** are electrically coupled to the devices **54** by the conductive plugs **58**.

[0017] The integrated circuit die **50** further includes pads **62**, such as aluminum pads, to which external connections are made. The pads **62** are on the active side of the integrated circuit die **50**, such as in and/or on the interconnect structure **60**. One or more passivation films **64** are on the integrated circuit die **50**, such as on portions of the interconnect structure **60** and pads **62**. Openings extend through the passivation films **64** to the pads **62**. Die connectors **66**, such as conductive pillars (for example, formed of a metal such as copper), extend through the openings in the passivation films **64** and are physically and electrically coupled to respective ones of the pads **62**. In some embodiments, die connectors **66** comprise under-bump metallization (UBM) structures. Although only four die connectors **66** are illustrated in FIG. **1**, there may be many more, as will be illustrated in later illustrations of the integrated circuit dies **50**. The die connectors **66** (e.g., copper pillars) may be formed by, for example, plating, or the like. The die connectors **66** electrically couple the respective integrated circuits of the integrated circuit die **50**.

[0018] Optionally, solder regions (e.g., solder balls or solder bumps, not shown) may be disposed on the pads **62** and/or the die connectors **66**. The solder regions may be used to perform chip probe (CP) testing on the integrated circuit die **50**. CP testing may be performed on the integrated circuit die **50** to ascertain whether the integrated circuit die **50** is a known good die (KGD). Thus, only integrated circuit dies **50**, which are KGDs, undergo subsequent processing are packaged, and integrated circuit dies **50** which fail the CP testing are not packaged. After testing, the solder regions may be removed in subsequent processing steps.

[0019] A dielectric layer **68** may (or may not) be on the active side of the integrated circuit die **50**, such as on the passivation films **64** and the die connectors **66**. The dielectric layer **68** laterally encapsulates the die connectors **66**, and the dielectric layer **68** is laterally coterminous with the integrated circuit die **50** after singulation. Initially, the dielectric layer **68** may bury the die connectors **66**, such that the topmost surface of the dielectric layer **68** is above the topmost surfaces of the die connectors **66**. In some embodiments where solder regions are disposed on the die connectors **66**, the dielectric layer **68** may also bury the solder regions. Alternatively, the solder

regions may be removed prior to forming the dielectric layer **68**.

[0020] The dielectric layer **68** may be a polymer such as PBO, polyimide, BCB, or the like; a nitride such as silicon nitride or the like; an oxide such as silicon oxide, PSG, BSG, BPSG, or the like; the like, or a combination thereof. The dielectric layer **68** may be formed, for example, by spin coating, lamination, chemical vapor deposition (CVD), or the like. In some embodiments, the die connectors **66** are exposed through the dielectric layer **68** during formation of the integrated circuit die **50**. In some embodiments, the die connectors **66** remain buried and are exposed during a subsequent process for packaging the integrated circuit die **50**. Exposing the die connectors **66** may remove any solder regions that may be present on the die connectors **66**.

[0021] At some point in the process, an adhesive layer **70** may be applied to a back side of the integrated circuit die **50**. In some embodiments, the adhesive layer is formed over the back side of the integrated circuit die **50** prior to attaching the integrated circuit die to a semiconductor package component as discussed in greater detail below.

[0022] In some embodiments, the integrated circuit die **50** is a stacked device that includes multiple semiconductor substrates **52**. For example, the integrated circuit die **50** may be a memory device such as a hybrid memory cube (HMC) module, a high bandwidth memory (HBM) module, or the like that includes multiple memory dies. In such embodiments, the integrated circuit die **50** includes multiple semiconductor substrates **52** interconnected by through-substrate vias (TSVs). Each of the semiconductor substrates **52** may (or may not) have an interconnect structure **60**.

[0023] The following describes the formation of a semiconductor package incorporating the integrated circuit die **50** in accordance with some embodiments. FIGS. 2A through 2G describe various intermediate steps in the formation of a first component, in accordance with some embodiments. As will be discussed, the first component may comprise a fan-out redistribution structure with an integrated circuit die **50** attached. FIGS. 3A through 3H describe the formation of a second component, which may be attached to the first component described with reference to FIGS. 2A through 2G, in accordance with some embodiments. As will be discussed, the second component may comprise a substrate-type redistribution structure. Although not specifically described, the second component may comprise a fan-out redistribution structure similar to that of the first component. FIGS. 4A through 4H describe attaching the second component to the first component and further processing to form a semiconductor package, in accordance with some embodiments.

[0024] Referring first to FIG. 2A, in the formation of a first component **100**, a first carrier substrate **102** is provided, and a release layer **104** is formed on the first carrier substrate **102**. The first carrier substrate **102** may be a glass carrier substrate, a ceramic carrier substrate, or the like. The first carrier substrate **102** may be a wafer, such that multiple packages can be formed on the first carrier substrate **102** simultaneously, wherein each package may contain one or more dies. The release layer **104** may be formed of a polymer-based material, which may be removed along with the first carrier substrate **102** from the overlying structures that will be formed in subsequent steps. In some embodiments, the release layer **104** is an epoxy-based thermal-release material, which loses its adhesive property when heated, such as a light-to-heat-conversion (LTHC) release coating. In some embodiments, the release layer **104** may be an ultra-violet (UV) glue, which loses its adhesive property when exposed to UV lights. The release layer **104** may be dispensed as a liquid and cured, may be a laminate film laminated onto the first carrier substrate **102**, or may be the like.

[0025] In FIGS. 2B-2E, a first-side redistribution structure **106** may be formed on the release layer **104**. In the embodiment shown, the first-side redistribution structure **106** includes one or more dielectric layers and metallization patterns (sometimes referred to as redistribution layers or redistribution lines). The first-side redistribution structure **106** will be described as having three layers of metallization patterns. More or fewer dielectric layers and metallization patterns may be formed in the first-side redistribution structure **106**. If fewer dielectric layers and metallization patterns are to be formed, steps and process discussed below may be omitted. If more dielectric

layers and metallization patterns are to be formed, steps and processes discussed below may be repeated.

[0026] Referring now to FIG. 2B, a dielectric layer **110** is formed on the release layer **104**. The bottom surface of the dielectric layer **110** may be in contact with the top surface of the release layer **104**. In some embodiments, the dielectric layer **110** is formed of a photo-sensitive material such as polybenzoxazole (PBO), polyimide, benzocyclobutene (BCB), or the like, which may be patterned using a lithography mask. In some embodiments, the dielectric layer **110** is formed of a nitride such as silicon nitride; an oxide such as silicon oxide, phosphosilicate glass (PSG), borosilicate glass (BSG), boron-doped phosphosilicate glass (BPSG), or the like. The dielectric layer **110** may be formed by spin coating, lamination, CVD, the like, or a combination thereof. The dielectric layer **110** is patterned to form openings exposing portions of the release layer **104**. The patterning may be by an acceptable process, such as by exposing the dielectric layer **110** to light, developing, and curing when the dielectric layer **110** is a photo-sensitive material or by etching using, for example, an anisotropic etch.

[0027] A metallization pattern **112** is then formed on the dielectric layer **110**. The metallization pattern **112** includes line portions (also referred to as conductive lines) on and extending along the major surface of the dielectric layer **110**. The metallization pattern **112** further includes via portions (also referred to as conductive vias) extending through the dielectric layer **110** to physically and electrically couple the first-side redistribution structure **106** with external connectors that may be formed in later steps. As an example to form the metallization pattern **112**, a seed layer is formed over the dielectric layer **110** and in the openings extending through the dielectric layer **110**. In some embodiments, the seed layer is a metal layer, which may be a single layer or a composite layer comprising a plurality of sub-layers formed of different materials. In some embodiments, the seed layer comprises a titanium layer and a copper layer over the titanium layer. The seed layer may be formed using, for example, physical vapor deposition (PVD) or the like. A photoresist is then formed and patterned on the seed layer. The photoresist may be formed by spin coating or the like and may be exposed to light for patterning. The pattern of the photoresist corresponds to the metallization pattern **112**. The patterning forms openings through the photoresist to expose the seed layer. A conductive material is then formed in the openings of the photoresist and on the exposed portions of the seed layer. The conductive material may be formed by plating, such as electroplating or electroless plating, or the like. The conductive material may comprise a metal, like copper, titanium, tungsten, aluminum, or the like. The photoresist and portions of the seed layer on which the conductive material is not formed are removed. The photoresist may be removed by an acceptable ashing or stripping process, such as using an oxygen plasma or the like. Once the photoresist is removed, exposed portions of the seed layer are removed, such as by using an acceptable etching process, such as by wet or dry etching. The remaining portions of the conductive material and underlying portions of the seed layer form the metallization pattern **112**.

[0028] In FIG. 2C, a dielectric layer **114** is deposited on the metallization pattern **112** and dielectric layer **110**. The dielectric layer **114** may be formed and patterned in a manner similar to the dielectric layer **110**.

[0029] A metallization pattern **116** is then formed. The metallization pattern **116** includes line portions on and extending along the major surface of the dielectric layer **114**. The metallization pattern **116** further includes via portions extending through the dielectric layer **114** to physically and electrically couple the metallization pattern **112**. The metallization pattern **116** may be formed in a similar manner and of a similar material as the metallization pattern **112**. In some embodiments, the metallization pattern **116** has a different size than the metallization pattern **112**. For example, the conductive lines and/or vias of the metallization pattern **112** may be wider or thicker than the conductive lines and/or vias of the metallization pattern **116**. Further, the metallization pattern **112** may be formed to a greater pitch than the metallization pattern **116**.

[0030] In FIG. 2D, a dielectric layer **118** is deposited on the metallization pattern **116** and dielectric

layer **114**. The dielectric layer **118** may be formed and patterned in a manner similar to the dielectric layers **110** and/or **114**.

[0031] A metallization pattern **120** is then formed. The metallization pattern **120** includes line portions on and extending along the major surface of the dielectric layer **118**. The metallization pattern **120** further includes via portions extending through the dielectric layer **118** to physically and electrically couple the metallization pattern **116**. The metallization pattern **120** may be formed in a similar manner and of a similar material as the metallization patterns **112** and/or **116**.

[0032] In FIG. 2E, a dielectric layer **122** is deposited on the metallization pattern **120** and dielectric layer **118**. The dielectric layer **122** may be formed and patterned in a manner similar to the dielectric layer **110** to form openings **124**.

[0033] The dielectric layer **110** and metallization pattern **112** are the bottommost dielectric layer and metallization pattern, respectively, of the first-side redistribution structure **106**. As such, all of the intermediate dielectric layers and metallization patterns of the first-side redistribution structure **106** (e.g., dielectric layers **114**, **118**, and **122**, and the metallization patterns **116** and **120**) are disposed between the dielectric layer **110**/metallization pattern **112** and the components that will be subsequently formed or attached above the first-side redistribution structure **106**. In some embodiments, the metallization pattern **112** has a different size than the metallization patterns **116** and **120**. For example, the conductive lines of the metallization pattern **112** may have a thickness of about 0.5 μm to about 15 μm , or about 5 μm , and the conductive lines of the metallization patterns **116** and **120** may have a thickness of about 0.5 μm to about 15 μm , or about 5 μm . The ratio of the thickness of the metallization pattern **112** to the thickness of the metallization pattern **120** may be about 0.3 to about 3, or about 1. Further, the metallization pattern **112** may be formed to a greater pitch than the metallization patterns **116** and **120**. For example, the conductive lines of the metallization pattern **112** may have a pitch of about 1 μm to about 100 μm , or about 10 μm , and the conductive lines of the metallization patterns **116** and **120** may have a pitch of about 1 μm to about 100 μm , or about 10 μm . The ratio of the pitch of the metallization pattern **112** to the pitch of the metallization pattern **120** may be about 0.1 to about 10, or about 1. It should be appreciated that the first-side redistribution structure **106** may include any number of dielectric layers and metallization patterns. If more dielectric layers and metallization patterns are to be formed, steps and processes discussed above may be repeated.

[0034] In FIG. 2F, through vias **126** are formed in some of the openings **124** and extending away from the topmost dielectric layer of the first-side redistribution structure **106** (e.g., the dielectric layer **122**). As an example to form the through vias **126**, a seed layer (not shown) is formed over the first-side redistribution structure **106**, e.g., on the dielectric layer **122** and portions of the metallization pattern **120** exposed by the openings. In some embodiments, the seed layer is a metal layer, which may be a single layer or a composite layer comprising a plurality of sub-layers formed of different materials. In some embodiments, the seed layer comprises a titanium layer and a copper layer over the titanium layer. In some embodiments, that seed layer is made of copper, titanium, nickel, gold, palladium, the like, or a combination thereof. The seed layer may be formed using, for example, PVD or the like. A mask, such as a photoresist (not shown), is formed and patterned on the seed layer. The photoresist may be formed by spin coating or the like and may be exposed to light for patterning. The pattern of the photoresist corresponds to the through vias **126** and exposes the seed layer. A conductive material is formed in the openings of the photoresist and on the exposed portions of the seed layer. The conductive material may be formed by plating, such as electro-chemical plating process or electroless plating, CVD, atomic layer deposition (ALD), PVD, the like, or a combination thereof. The conductive material may comprise a metal, like copper, titanium, tungsten, aluminum, or the like. The photoresist may be removed.

[0035] Still referring to FIG. 2F, bond pads **128** are formed in some of the openings **124** and extending away from the dielectric layer **122**. The bond pads **128** may be formed in a manner similar to the through vias **126**, and may be formed of the same material as the through vias **126**. In

addition, the bond pads **128** may be formed before, after, or simultaneously with the through vias **126**.

[0036] The photoresist used for the bond pads **128** and for the through vias **126** and portions of the seed layer on which the bond pads **128** and the through vias **126** are not formed are removed. The photoresist may be removed by an acceptable ashing or stripping process, such as using an oxygen plasma or the like. Once the photoresist is removed, exposed portions of the seed layer are removed, such as by using an acceptable etching process, such as by wet or dry etching. The remaining portions of the seed layer and conductive material form the bond pads **128** and the through vias **126**.

[0037] As discussed below, an integrated circuit die (such as integrated circuit die **50** discussed above with reference to FIG. **1**) may be attached to the bond pads **128**. In some embodiments, the bond pads **128** are UBMs that may include, for example, three layers of conductive materials, such as a layer of titanium, a layer of copper, and a layer of nickel. Other arrangements of materials and layers, such as an arrangement of chrome/chrome-copper alloy/copper/gold, an arrangement of titanium/titanium tungsten/copper, or an arrangement of copper/nickel/gold, may be utilized for the formation of the bond pads **128**. Any suitable materials or layers of material that may be used for the bond pads **128** are fully intended to be included within the scope of the current application.

[0038] In FIG. **2G**, one or more semiconductor devices, such as the first integrated circuit die **50**, are attached to the bond pads **128** to make electrical connection with the first-side redistribution structure **106**. For example, the first integrated circuit die **50** may be attached by forming solder joints **130** over the die connectors **66** (whether conductive pillars or UBMs), pressing the die connectors **66** to the bond pads **128**, and reflowing the solder joints **130** to attach the first integrated circuit die **50** to the first-side redistribution structure **106**. In some embodiments, the first integrated circuit die **50** may be attached using direct metal-to-metal bonding or hybrid bonding. FIG. **2G** depicts the integrated circuit die **50** as having a greater height than the through vias **126**. However, it may be appreciated that the through vias **126** may have about the same height or a greater height than the integrated circuit die **50**. For example, the through vias **126** may have a height $H_{\text{sub.TV}}$ of about 10 μm to about 200 μm , and the integrated circuit die **50** may have a height $H_{\text{sub.IC1}}$ of about 30 μm to about 250 μm . The ratio of height $H_{\text{sub.TV}}$ to height $H_{\text{sub.IC1}}$ may be about 0.04 to about 8.

[0039] It should be appreciated that the first-side redistribution structure **106** may be a fan-out redistribution structure with respect to the integrated circuit die **50**. As such, the metallization patterns (e.g., the metallization patterns **112**, **116**, and **120**) may extend further in a lateral direction than the integrated circuit die **50**. The fan-out design allows for a thinner redistribution structure while also accommodating a greater number of external connectors, which may therefore also extend further in a lateral direction than the integrated circuit die **50**. The first-side redistribution structure **106** is formed to a thickness $T_{\text{sub.1}}$, which may be about 20 μm to about 100 μm .

[0040] An underfill material **132** may be dispensed between the first integrated circuit die **50** and the first-side redistribution structure **106**. The underfill material **132** surrounds the solder joints **130** and bond pads **128**. The underfill material **132** may be any acceptable material, such as a polymer, epoxy, molding underfill, or the like. The underfill material **132** may be dispensed using a needle or a jetting dispenser, using a capillary flow process, or using another suitable process. In some embodiments, a curing process may be performed to cure the underfill material **132**. Although not explicitly shown in FIG. **2G**, the underfill material **132** may extend along sidewalls of the first integrated circuit die **50**.

[0041] FIG. **2G** illustrates a single integrated circuit die **50** attached to the bond pads **128** for illustrative purposes. In some embodiments, two or more integrated circuit dies **50** (each having a same or a different functionality) may be attached to the bond pads **128**.

[0042] FIGS. **3A** through **3H** illustrate cross-sectional views of intermediate steps during a process for forming a second component **200**, in accordance with some embodiments. As discussed above,

the second component **200** may be subsequently attached to the first component **100** discussed above with reference to FIGS. 2A-2G. The second component **200** may be formed as individual packages or through wafer-level processing. Only an individual package component **200** is illustrated, but it should be appreciated that the second component **200** may be part of a wafer. After formation, the individual second components **200** are singulated. The resulting second component **200** may also be referred to as an integrated package.

[0043] In FIG. 3A, a second carrier substrate **202** is provided, and a second-side redistribution structure may be formed on the second carrier substrate **202**. The second carrier substrate **202** may be a glass carrier substrate, a ceramic carrier substrate, or the like. The second carrier substrate **202** may be a wafer, such that multiple packages can be formed on the second carrier substrate **202** simultaneously. A first metal film **204** is formed on the second carrier substrate **202**. The first metal film **204** may comprise copper, such as a copper foil. The second carrier substrate **202** may have a thickness of about 10 μm to about 400 μm , or about 200 μm . The first metal film **204** may have a thickness of about 1 μm to about 20 μm , or about 3 μm . The first metal film **204** may comprise copper or another conductive material.

[0044] In FIG. 3B, a photoresist **208** is then formed and patterned on the first metal film **204**. The photoresist **208** may be formed by spin coating or the like and may be exposed to light for patterning. The patterning forms openings through the photoresist **208** to expose the first metal film **204**.

[0045] In FIG. 3C, a second-side redistribution structure **206** is formed over the first metal film **204**. First, a first metal trace **210** is formed over the first metal film **204**, and the photoresist **208** is removed. The first metal trace **210** may be formed by electro-plating and may comprise one or more layers of conductive material. For example, a layer of gold (Au) may be deposited first, a layer of nickel (Ni) next, and a layer of copper (Cu) last. The Au may be deposited at a thickness of greater than or about 0.1 μm , such as about 0.01 μm to about 3 μm . The nickel may be deposited at a thickness of greater than or about 3 μm , such as about 0.1 μm to about 10 μm . The copper may be deposited at a thickness of greater than or about 7 μm , such as about 1 μm to about 25 μm . As such, the first metal trace **210** may have a thickness of greater than or about 1 μm to about 35 μm , such as greater than or about 10 μm . Thicknesses such as these provide the benefit of adhering the first metal trace **210** to the first metal film **204**, maintaining internal cohesiveness, and/or allowing sufficient conductive properties. Thicknesses less than these may result in poorer adhesiveness, cohesiveness, and/or conductivity. The photoresist **208** may be removed by any suitable stripping method.

[0046] In FIG. 3D, a dielectric layer **212** is formed over the first metal trace **210**. The dielectric layer **212** may be formed by a thermal lamination process. The dielectric layer **212** may comprise prepreg or Ajinomoto Build-up Film (ABF). In some embodiments, the dielectric layer **212** may be prepreg with a thickness of about 10 μm to about 100 μm , such as about 30 μm , or ABF with a thickness of about 10 μm to about 100 μm , such as about 20 μm . A benefit of using prepreg or ABF material as the dielectric layer **212** is that the second-side redistribution structure **206** will have a high level of strength and reliability. When later coupled with the first-side redistribution structure **106**, the overall semiconductor package will be less susceptible to warpage.

[0047] In FIG. 3E, the dielectric layer **212** is patterned to form openings exposing portions of the first metal trace **210**. The openings include via openings **214** extending through the dielectric layer **212** to expose a portion of the first metal trace **210**. The openings further include line openings **216** that connect with the via openings **214** and provide routing capabilities. The dielectric layer **212** can be patterned using a single damascene or a dual damascene process. The patterning may be performed by any suitable method, such as forming a photoresist and wet or dry etching the dielectric layer **212** and/or employing a laser ablation (or laser drilling) technique. Although depicted with vertical sidewalls, it should be appreciated that a laser drilling technique may result in the via openings **214** having non-vertical sidewalls. The via openings **214** may have a width of

about 30 μm to about 150 μm , such as about 65 μm .

[0048] In FIG. 3F, the via openings **214** and the line openings **216** in the upper region of the dielectric layer **212** are filled with a conductive material to form conductive vias **218** (in the via openings **214**) and second metal traces **220** (in the line openings **216**). The conductive material may be deposited by electro-plating or electroless-plating, or any suitable method. The second metal traces **220** may have a thickness of about 10 μm . Alternatively, the conductive vias **218** may be initially formed before the dielectric layer **212** is patterned to form the second metal trace **220**.

[0049] The second-side redistribution structure **206** (comprising the first metal trace **210**, the conductive vias **218**, and the second metal trace **220**) is formed to a thickness $T_{\text{sub.2}}$, which may be about 20 μm to about 150 μm . Thickness $T_{\text{sub.2}}$ of the second-side redistribution structure **206** may be greater than or equal to thickness $T_{\text{sub.1}}$ of the backside redistribution structure **106**. The ratio of thickness $T_{\text{sub.2}}$ to thickness $T_{\text{sub.1}}$ may be about 0.3 to about 3. A ratio in this range provides a suitable stiffness to prevent or reduce warpage due to the differences in the coefficient of thermal expansions (CTEs) of, for example, the dielectric layers and the metallization patterns of the first-side redistribution structure **106** when the second component **200** is subsequently attached to the first component **100**, and the materials comprising the integrated circuit die **50**. Ratios less than these values may not provide a sufficient stiffness for the second component **200** to counterbalance the expansion of the components of the first component **100**. Ratios greater than these values may increase the signal lengths, thereby reducing the performance of the packaged device.

[0050] In FIG. 3G, a solder resist **222** is formed and patterned to form openings **224** exposing the conductive vias **218** and/or the second metal trace **220**. In addition, the exposed portions of the conductive vias **218** and the second metal trace **220** may be treated for protective purposes. For example, an electroless nickel electroless palladium immersion gold (ENEPIG) treatment or an organic solderability preservative (OSP) may be performed on exposed portion of the conductive vias **218** and the second metal trace **220**. The solder resist may have a thickness of about 5 μm to about 40 μm , such as about 10 μm . The solder resist **222** may also be used to protect areas of the second-side redistribution structure **206** from external damage.

[0051] In FIG. 3H, connectors **226** are formed over the exposed portions of the conductive vias **218** and the second metal trace **220**. The connectors **226** may be solder balls formed in a manner similar to the solder regions on the first integrated circuit die **50**, and may be formed of a similar material as the solder regions on the first integrated circuit die **50**.

[0052] In the case of wafer level processing to form the second component **200**, a singulation process may be performed by sawing along scribe regions between adjacent second components **200**. As discussed below the resulting, singulated second component **200** is coupled to the first component **100**. In some embodiments, the first component **100** is similarly singulated before the second component **200** is attached. In some embodiments, the first component **100** is singulated after attaching the second component **200**.

[0053] FIGS. 4A through 4H illustrate cross-sectional views of intermediate steps for attaching the second component **200** to the first component **100**, as well as additional processing, to form a package **400**, in accordance with some embodiments.

[0054] Referring first to FIG. 4A, the package **400** is illustrated in which the first component **100** is part of a wafer. In some embodiments (but not illustrated in FIG. 4A), the first component **100** has already been singulated at the scribe region **404**.

[0055] Each singulated second component **200** is mounted to a first component **100** using the connectors **226**. As discussed above, the first component **100** includes through vias **126** for attachment. As such, the connectors **226** are bonded to corresponding through vias **126**. In some embodiments, the connectors **226** are reflowed to attach the second component **200** to the through vias **126**. The connectors **226** electrically couple the second component **200** to the first-side redistribution structure **106** of the first package component **100**. The connectors **226** may have an

epoxy flux (not shown) formed thereon before they are reflowed with at least some of the epoxy portion of the epoxy flux remaining after the second component **200** is attached to the first component **100**. This remaining epoxy portion may act as an underfill to reduce stress and protect the joints resulting from the reflowing the connectors **226**. After attaching the second component **200** to the first component **100**, the first-side redistribution structure **106** and the second-side redistribution structure **206** may be separated from one another by a thickness $T_{sub.3}$. The thickness $T_{sub.3}$ may be about 50 μm to about 500 μm . The ratio of thickness $T_{sub.3}$ to thickness $T_{sub.1}$ may be about 0.4 to about 5. The ratio of thickness $T_{sub.3}$ to thickness $T_{sub.2}$ may be about 0.3 to about 4.

[0056] In FIG. **4B**, an encapsulant **310** is formed over the first component **100** and below and around the second component **200**. The encapsulant **310** further encapsulates the through vias **126**, the first integrated circuit die **50**, and any other devices (if any) attached to the first component **100** and/or the second component **200**. The encapsulant **310** is further formed in gap regions between adjacent second components **200**. The encapsulant **310** may be formed by a capillary flow process after the second package component **200** is attached or may be formed by a suitable deposition method before the second package component **200** is attached. In some embodiments, the encapsulant **310** may be applied by compression molding, transfer molding, or the like. The encapsulant **310** may be applied in liquid or semi-liquid form and then subsequently cured. The encapsulant **310** may be a molding compound, epoxy, or the like.

[0057] As represented in insets **401** and **402** of FIG. **4B**, the encapsulant **310** may be formed around lateral edges of the second-side redistribution structure **206** of the second component **200**. The encapsulant **310** may partially or completely cover a lateral edge of the second component **200**. For example, as depicted in inset **401**, the encapsulant **310** may have a recessed upper surface with a highest point located proximate to a lateral edge of the second component **200**. The encapsulant **310** may partially or completely cover a lateral edge of the second-side redistribution structure **206**. In some embodiments, the encapsulant **310** may further cover a portion of a lateral edge of the second carrier substrate **202**. In addition, a lowest point on the upper surface may be below the portion of the second-side redistribution structure **206** that is closest to the second carrier substrate **202**. As depicted in inset **402**, the encapsulant **310** may be formed to cover all of a lateral edge of the second-side redistribution structure **206** as well as all or part of a lateral edge of the second carrier substrate **202**. In some embodiments, the encapsulant **310** may cover the entirety of the lateral edges of the second carrier substrate **202** and even part of an upper surface of the second carrier substrate **202** (not specifically illustrated).

[0058] The encapsulant **310** provides additional support to the second-side redistribution structure **206**, which makes the overall package **400** stronger, more reliable, and less susceptible to warpage. As discussed above, added strength and sturdiness come from the upper portion of the encapsulant **310** adhering to the lateral edges of the second component **200**. The encapsulant **310** may slope downward away from the lateral edges of the second component **200** as depicted in inset **401** of FIG. **4B**. The slope may have an angle θ from the horizontal. The angle θ may be about 0 degrees to about 45 degrees, or about 45 to about 60 degrees.

[0059] In FIG. **4C**, the second carrier substrate **202** is removed from the package **400** exposing the second-side redistribution structure **206**, in accordance with some embodiments. The second carrier substrate **202** may be demounted, debonded, or mechanically peeled off from the second-side redistribution structure **206** using, e.g., a thermal process to alter the adhesive properties of a release layer disposed on the second carrier substrate **202**. In some embodiments an energy source such as an ultraviolet (UV) laser, a carbon dioxide ($\text{CO}_{sub.2}$) laser, or an infrared (IR) laser, is utilized to irradiate and heat the release layer until the release layer loses at least some of its adhesive properties. Once performed, the second carrier substrate **202** and the metal film **204** may be physically separated and removed from the second-side redistribution structure **206**. In some embodiments, a planarization process or a mechanical peel-off process is performed to remove the

second carrier substrate **202** to expose the second-side redistribution structure **206**. The planarization process may also remove some of the encapsulant **310** that may have been formed above an upper level of the second-side redistribution structure **206**. The planarization process may be, for example, a chemical-mechanical polish (CMP), a grinding process, or the like. It should be noted that, even in embodiments in which the encapsulant **310** is formed to completely cover the lateral edge of the second component (and perhaps over the upper surface of the second carrier substrate **202** (e.g., as generally depicted in inset **402** of FIG. **4B**)), the package **400** is not susceptible to mold creep of the encapsulant **310** over an upper surface of the second-side redistribution structure **206** due to the protection of the second carrier substrate **202**. As such, after removal of the second carrier substrate **202**, the upper surface of the second-side redistribution structure **206** is free of the encapsulant **310**. As such, a topmost surface of the encapsulant **310** may be level with or recessed from the upper surface of the second-side redistribution structure **206**.

[0060] Still referring to FIG. **4C**, in some embodiments, passivation layer **320** is formed and patterned over the exposed second-side redistribution structure **206**. The passivation layer **320** may be a dielectric material formed in a manner and of a material similar to any one of the dielectric layers **110**, **114**, **118**, and **122**. Alternatively, the passivation layer **320** may be a solder resist formed in a manner and of a material similar to the solder resist **222**.

[0061] In FIG. **4D**, the package **400** may be flipped over and attached to a temporary substrate **406**, such as a tape, wafer, panel, frame, ring, or the like. The first carrier substrate **102** is then removed. In some embodiments, a carrier substrate de-bonding is performed to detach (or demount or de-bond) the first carrier substrate **102** from the first-side redistribution structure **106**, e.g., the dielectric layer **110**. In accordance with some embodiments, the de-bonding includes projecting a light such as a laser light or an UV light on the release layer **104** so that the release layer **104** decomposes under the heat of the light and the first carrier substrate **102** can be removed.

[0062] In FIG. **4E**, conductive connectors **410** are formed on the first-side redistribution structure **106**. The conductive connectors **410** may be ball grid array (BGA) connectors, solder balls, metal pillars, controlled collapse chip connection (C4) bumps, micro bumps, electroless nickel-electroless palladium-immersion gold technique (ENEPIG) formed bumps, or the like. The conductive connectors **410** may include a conductive material such as solder, copper, aluminum, gold, nickel, silver, palladium, tin, the like, or a combination thereof. In some embodiments, the conductive connectors **410** are formed by initially forming a layer of solder through evaporation, electroplating, printing, solder transfer, ball placement, or the like. Once a layer of solder has been formed on the structure, a reflow may be performed in order to shape the material into the desired bump shapes. In another embodiment, the conductive connectors **410** comprise metal pillars (such as a copper pillar) formed by a sputtering, printing, electro plating, electroless plating, CVD, or the like. The metal pillars may be solder free and have substantially vertical sidewalls. In some embodiments, a metal cap layer is formed on the top of the metal pillars. The metal cap layer may include nickel, tin, tin-lead, gold, silver, palladium, indium, nickel-palladium-gold, nickel-gold, the like, or a combination thereof and may be formed by a plating process.

[0063] If it has not already, the structure may then be singulated along the scribe region **404** (see, e.g., FIG. **4A**) to form individual packages **400**, in accordance with some embodiments.

Alternatively, the structure is singulated before forming conductive connectors **410**. In some embodiments, the structure may be singulated using one or more saw blades that separate the package **400** into discrete pieces, forming one or more singulated packages **400**. However, any suitable method of singulation, including laser ablation or one or more wet etches, may also be utilized.

[0064] After singulation, the first-side redistribution structure **106** has a width $W_{sub.1}$, which may be about 3 mm to about 150 mm. The second component **200** and its second-side redistribution structure **206** has a width $W_{sub.2}$, which may be about 3 mm to about 150 mm. The width $W_{sub.2}$ may be less than or equal to width $W_{sub.1}$ (e.g., the width of the first component **100** and its first-

side redistribution structure **106**). The ratio of the width W.sub.1 to the width W.sub.2 may be about 1 to about 3, or about 1. A ratio in this range provides an overall semiconductor package less susceptible to warpage when the second-side redistribution structure **206** is coupled to the first-side redistribution structure **106**. In other words, the strength of the second-side redistribution structure **206** and the width W.sub.2 will balance out warpage that may otherwise occur from the first-side redistribution structure **106**.

[0065] In FIGS. **4F** and **4G**, after singulation, the package **400** may be removed from the temporary substrate **406** and flipped over and attached to another substrate, such as substrate **420** (e.g., a carrier substrate, package substrate, PCB, or the like). As shown, the package **400** may feature the passivation layer **320** (FIG. **4F**) or the passivation layer **320** may be omitted (FIG. **4G**). In some cases within a package **400**, the through via **126** may align with a conductive via **218** as depicted in the expanded portion of FIG. **4G**. Depending on the method of formation, the conductive via **218** may have inwardly sloping sidewalls. In some cases the inwardly sloping sidewalls may have a concave shape giving the conductive via **218** an hourglass shape. In addition, the conductive via **218** may have tooth-like sidewalls. The tooth-like sidewalls may be due, in part, to the laser ablation method of drilling through the dielectric layer **212** as discussed above in connection with FIG. **3F**.

[0066] In FIG. **4H**, there is illustrated an embodiment similar to that discussed above with reference to FIG. **4F** in which additional devices **450** are attached to the substrate **420**. The additional devices **450** may include active devices and/or passive devices, such as integrated passive devices and surface mount devices (SMD) (e.g., capacitors). In addition, the additional devices **450** may include devices similar to the integrated circuit die **50** and devices designed for an intended purpose such as a memory die (e.g., a DRAM die, a stacked memory die, a high-bandwidth memory (HBM) die, etc.), a logic die, a central processing unit (CPU) die, a system-on-a-chip (SoC), a component on a wafer (CoW), an integrated fan-out structure (InFO), a package, the like, or a combination thereof.

[0067] FIGS. **5A** through **5H** and FIGS. **6A** through **6H** describe various intermediate steps in the formation of a first component (including a first integrated circuit die **50**), formation of a second component (including attachment of a second integrated circuit die **50**), and attaching the second component to the first component and further processing to form a semiconductor package, in accordance with some embodiments.

[0068] FIGS. **5A** through **5H** illustrate cross-sectional views of intermediate steps for forming a first component **501**, a second component **502**, and a package **504**, in accordance with some embodiments. In particular, the figures depict certain intermediate steps in the formation of the first component **501**, attachment of the second component **502** to the first component **501**, as well as additional processing, to form a package **504**.

[0069] In FIG. **5A**, the first-side redistribution structure **106** of the first component **501** has been provided, and through vias **126** and bond pads **128** have been formed over the first-side redistribution structure **106**. Processes and materials similar to those discussed above with reference to FIGS. **2A-2F** may be used. In FIG. **5B**, the first integrated circuit die **50** has been attached along with one or more other semiconductor devices **550** (only one is illustrated, though there may be a plurality of additional semiconductor devices). Processes and materials similar to those discussed above with reference to FIG. **2G** may be used.

[0070] The first integrated circuit die **50** and other devices **550** may include devices designed for an intended purpose such as a memory die (e.g., a DRAM die, a stacked memory die, a high-bandwidth memory (HBM) die, etc.), a logic die, a central processing unit (CPU) die, a system-on-a-chip (SoC), a component on a wafer (CoW), an integrated fan-out structure (InFO), a package, the like, or a combination thereof. The first integrated circuit die **50** and other devices **550** may be formed in processes of a same technology node, or may be formed in processes of different technology nodes. For example, the first integrated circuit die **50** may be of a more advanced

process node than the other devices **550**. The first integrated circuit die **50** and other devices **550** may have different sizes (e.g., different heights and/or surface areas), or may have the same size (e.g., same heights and/or surface areas). A benefit of the first-side redistribution structure **106** is to provide electrical connectivity between the integrated circuit die **50**, the other devices **550**, the subsequently attached second component **502**, and components subsequently attached to the other side of the first-side redistribution structure **106**.

[0071] In some embodiments, the first integrated circuit die **50** and other devices include transistors, capacitors, inductors, resistors, metallization layers, external connectors, and the like, therein, as desired for a particular functionality. In some embodiments, the first integrated circuit die **50** and other devices may include more than one of the same type of device, or may include different devices. FIG. 5B shows a single integrated circuit die **50**, but in some embodiments one, two, or more integrated circuit dies **50** or other devices may be attached to the first-side redistribution structure **106**. FIG. 5B depicts the integrated circuit die **50** as having a lesser height than the through vias **126**. This is to accommodate the second component **502**, which will include another integrated circuit die (as shown in later figures). For example, the through vias **126** may have a height $H_{sub.TV}$ of about 10 μm to about 200 μm , and the integrated circuit die **50** may have a height $H_{sub.IC1}$ of about 30 μm to about 250 μm . The ratio of height $H_{sub.TV}$ to height $H_{sub.IC1}$ may be about 0.04 to about 8.

[0072] In FIG. 5C, the second-side redistribution structure **206** of the second component **502** has been provided, and the solder resist **222** may be formed and patterned to form openings **228** in addition to the openings **224**. Processes and materials similar to those discussed above with reference to FIGS. 3A-3H may be used. Some or all of the openings **228** may expose portions of the conductive vias **218** and the second metal trace **220**. The openings **228** may be formed at the same time as the openings **224** or at a different time using the same or different patterning method.

[0073] In FIG. 5D, a second integrated circuit die **50** may be attached to the second-side redistribution structure **206** at the openings **228** and electrically coupled to the conductive vias **218** and the second metal trace **220**. Processes and materials similar to those discussed above with reference to FIGS. 2G and 5B may be used, including formation of bond pads **528**, solder joints **530**, and underfill material **532**. In addition, connectors **226** may be formed in the openings **224**.

[0074] In FIG. 5E, the second component **502**, comprising the second-side redistribution structure **206** and the second integrated circuit die **50**, is attached to the first component **501** and the second carrier substrate **202** is removed using processes and materials similar to those discussed above with reference to FIGS. 4A through 4C. As discussed above in reference to the package **400**, the package **504** may have the width $W_{sub.1}$ of the first-side redistribution structure **106** greater than the width $W_{sub.2}$ of the second-side redistribution structure **206**, and the encapsulant **310** may be formed around lateral edges of the second-side redistribution structure **206**, similarly as shown in FIGS. 4B through 4H. As shown, the second component **502** is attached such that the backsides of the first integrated circuit die **50** and the second integrated circuit die **50** face one another. Either or both of the first and the second integrated circuit dies **50** may have a dielectric layer **510** along the backside, which may then be directly interposed between the first and the second integrated circuit dies **50**.

[0075] Still referring to FIG. 5E, the dielectric layer **510** may be similar to the adhesive layer **70** and applied in a similar manner. The first and the second integrated circuit dies **50** may be vertically aligned such that at least a portion of the second integrated circuit die **50** is directly over at least a portion of the first integrated circuit die **50**. The first and the second integrated circuit dies **50** may be centered with one another or, alternatively, asymmetrically positioned.

[0076] The package **504** may then be completed as shown in FIGS. 5F through 5H and in a similar manner as described above, such as in connection with FIGS. 4D through 4H. As shown in FIG. 5G, a third integrated circuit die **50** may be attached to the first-side redistribution structure **106** using processes and materials similar to those discussed above with reference to FIGS. 2G, 5B, and

5D. And as shown in FIG. 5H, a fourth integrated circuit die **50** and additional devices **550** may be attached to the second-side redistribution structure **206** using processes and materials similar to those discussed above with reference to FIGS. 2G, 4H, 5B and 5D. A benefit of the depicted layout includes allowing for a narrower package **504** in the horizontal direction and/or providing more space along the first-side redistribution structure **106** to attach additional devices.

[0077] As discussed above, the first-side redistribution structure **106** and the second-side redistribution structure **206** are separated by the thickness $T_{\text{sub.3}}$. In this embodiment, the thickness $T_{\text{sub.3}}$ may be about 60 μm to about 500 μm . The ratio of thickness $T_{\text{sub.3}}$ to thickness $T_{\text{sub.1}}$ may be about 0.5 to about 25. The ratio of thickness $T_{\text{sub.3}}$ to thickness $T_{\text{sub.2}}$ may be about 0.4 to about 25. In addition, the connectors **226** may have a height H_e that is about 10 μm to about 300 μm , or about 150 μm . As such, the total height of the through via **126** and the connector **226** in the package **504** may be about 50 μm to about 500 μm , or about 250 μm (noting that the total height may be less than the sum of the height H_c and the height $H_{\text{sub.TV}}$ due to reflowing the connector **226**), which will be substantially the same as thickness $T_{\text{sub.3}}$ of the region between the first-side redistribution structure **106** and the second-side redistribution structure **206**. As further shown in FIG. 5H, the total height of the first integrated circuit die **50** and the second integrated circuit die (height $H_{\text{sub.IC1}}$ and height $H_{\text{sub.IC2}}$, respectively, plus a thickness of the dielectric layer **510**) will be substantially the same as thickness $T_{\text{sub.3}}$.

[0078] FIGS. 6A through 6H illustrate cross-sectional views of intermediate steps for forming the package **604**, in accordance with some embodiments. In particular, the figures depict certain intermediate steps in the formation of the first component **601**, attachment of the second component **602** to the first component **601**, as well as additional processing, to form a package **604**.

[0079] In FIG. 6A, the first-side redistribution structure **106** of the first component **601** has been provided, and through vias **126** and bond pads **128** have been formed over the first-side redistribution structure **106**. Processes and materials similar to those discussed above with reference to FIGS. 2A-2F and 5A may be used. In FIG. 6B, the first integrated circuit die **50** is attached along with one or more other semiconductor devices **650**. Processes and materials similar to those discussed above with reference to FIGS. 2G and 5B may be used. FIG. 6B depicts the integrated circuit die **50** as having a lesser height than the through vias **126**. This is to accommodate the second component **602**, which will include another integrated circuit die **50**. For example, the through vias **126** may have a height $H_{\text{sub.TV}}$ of about 10 μm to about 300 μm , and the integrated circuit die **50** may have a height $H_{\text{sub.IC1}}$ of about 30 μm to about 300 μm . The ratio of height $H_{\text{sub.TV}}$ to height $H_{\text{sub.IC1}}$ may be about 0.03 to about 10.

[0080] In FIG. 6C, the second-side redistribution structure **206** of the second component **602** has been provided, and the solder resist **222** may be formed and patterned to form openings **228** in addition to the openings **224**. Processes and materials similar to those discussed above with reference to FIGS. 3A-3H and 5C may be used. Some or all of the openings **228** may expose portions of the conductive vias **218** and the second metal trace **220**. The openings **228** may be formed at the same time as the openings **224** or at a different time using the same or different patterning method.

[0081] In FIG. 6D, a second integrated circuit die **50** may be attached to the second-side redistribution structure **206** at the openings **228** and electrically coupled to the conductive vias **218** and the second metal trace **220**. Processes and materials similar to those discussed above with reference to FIGS. 2G, 5B, 5D, and 6B may be used, including formation of bond pads **628**, solder joints **630**, and underfill material **632**.

[0082] In FIG. 6E, the second component **602**, comprising the second-side redistribution structure **206** and the second integrated circuit die **50**, is attached to the first component **601** and the second carrier substrate **202** is removed using processes and materials similar to those discussed above with reference to FIGS. 4A through 4C and 5E. As discussed above in reference to the packages **400** and **504**, the package **604** may have the width $W_{\text{sub.1}}$ of the first-side redistribution structure

106 greater than the width $W_{sub.2}$ of the second-side redistribution structure **206** and the encapsulant **310** may be formed around lateral edges of the second-side redistribution structure **206**, similarly as shown in FIGS. **4B** through **4H**. As shown, the second component **602** is attached such that the second integrated circuit die **50** is laterally displaced from the first integrated circuit die **50**. The lateral displacement allows for the backside surface of the second integrated circuit die **50** to be lower than the backside surface of the first integrated circuit die **50**, although the backside surfaces may be at the same level or the backside surface of the second integrated circuit die **50** may be higher than the backside surface of the first integrated circuit die **50**.

[0083] The package **604** may then be completed as shown in FIGS. **6F** through **6H** and in a similar manner as described above, such as in connection with FIGS. **4D** through **4H** and **5F** through **5H**. As shown in FIG. **6G**, a third integrated circuit die **50** may be attached to the first-side redistribution structure **106** using processes and materials similar to those discussed above with reference to FIGS. **2G**, **5B**, and **5D**, **6B**, and **6D**. In addition, external connectors **610** may be formed to provide means to subsequently attach other integrated circuit devices or packages. And as shown in FIG. **6H**, a fourth integrated circuit die **50** and additional devices **650** may be attached to the second-side redistribution structure **206** using processes and materials similar to those discussed above with reference to FIGS. **2G**, **4H**, **5B**, **5D**, **5G**, **5H**, **6B**, **6D**, and **6G**. A benefit of this layout includes allowing for a thinner package **604**.

[0084] As discussed above, the first-side redistribution structure **106** and the second-side redistribution structure **206** are separated by the thickness $T_{sub.3}$. In this embodiment, the thickness $T_{sub.3}$ may be about 50 μm to about 500 μm . The ratio of thickness $T_{sub.3}$ to thickness $T_{sub.1}$ may be about 0.4 to about 25. The ratio of thickness $T_{sub.3}$ to thickness $T_{sub.2}$ may be about 0.03 to about 10. In addition, the connectors **226** may have a height H_e that is about 10 μm to about 300 μm , or about 150 μm . As such, the total height of the through via **126** and the connector **226** in the package **604** may be about 100 μm to about 600 μm , or about 300 μm (noting that the total height may be less than the sum of the height H_e and the height $H_{sub.TV}$ due to reflowing the connector **226**), which will be substantially the same as thickness $T_{sub.3}$ of the region between the first-side redistribution structure **106** and the second-side redistribution structure **206**. As further shown in FIG. **6H**, the thickness $T_{sub.3}$ is less than what the total height would be for stacking the first integrated circuit die **50** and the second integrated circuit die (height $H_{sub.IC1}$ and height $H_{sub.IC2}$, respectively). In other words, the lateral displacement of the first and second integrated circuit dies **50** with respect to one another allows for a lower thickness $T_{sub.3}$. In some embodiments, the thickness of the encapsulant **310** between the first-side redistribution structure **106** and the backside surface of the second integrated circuit die **50** may be about 30 μm to about 300 μm , such as about 150 μm . In addition, the thickness of the encapsulant **310** between the second-side redistribution structure **206** and the first integrated circuit die **50** may be about 30 μm to about 300 μm , such as about 150 μm .

[0085] Embodiments may achieve advantages for system in package (SiP) structures for integrated circuits. For example, dual-sided routing (e.g., second-side and first-side redistribution structures) allows for each side of routing to be thinner and for a thinner overall semiconductor package while reducing overall package warpage. In addition, the carrier-type substrate used in one of the routing structures provides greater structural support, which also reduces overall package warpage. Further, the methodology described provides versatility in layout of the embedded integrated circuit dies and other devices. Indeed, vertically stacking the integrated circuit dies may provide sufficient space for additional devices to be attached to the first-side redistribution structure, whereas laterally displacing the integrated circuit dies may allow for an overall thinner package structure. It should also be appreciated that the first-side redistribution structure may be wider than the second-side redistribution structure, which permits the encapsulant to be formed around the second-side redistribution structure to strengthen the package and further reduce overall package warpage. Indeed, the methodology described provides for application of the encapsulant in such a way that

there is no risk of mold creep along the outer surface of the second-side redistribution structure. This ensures that additional devices may be attached to the outer surface of the second-side redistribution structure without interference from trace amounts of encapsulant.

[0086] In an embodiment, a semiconductor package is fabricated by attaching a first component to a second component. The first component is assembled by forming a first redistribution structure over a substrate. A through via is then formed over the first redistribution structure, and a die is attached to the first redistribution structure active-side down. The second component includes a second redistribution structure, which is then attached to the through via. A molding compound is deposited between the first redistribution structure and the second redistribution structure and further around the sides of the second component.

[0087] In another embodiment, a semiconductor package is fabricated by forming a first component, forming a second package component, and attaching the second component to the first component. The first component is formed by forming a redistribution structure over a substrate, forming a through via over the redistribution structure, and attaching a die to the redistribution structure. The second component is formed by forming another redistribution structure over another substrate, forming a connector over this redistribution structure, and attaching another die to this redistribution structure. The second component is attached by flipping it over and bonding the connector to the through via by reflowing the connector. After attachment, the substrate is removed from the second component.

[0088] In yet another embodiment, a semiconductor package includes a first redistribution structure on a substrate and a second redistribution structure stacked on top of the first redistribution structure. The second redistribution structure includes a conductive via. The first redistribution structure is wider than the second redistribution structure. A through via electrically couples the first redistribution structure to the second redistribution structure. A die is attached to the first redistribution structure with the active side of the die facing and electrically coupled to the first redistribution structure. Another die is attached to the second redistribution structure with the active side of this die facing and electrically coupled to the second redistribution structure. An encapsulant fills in the region between the first redistribution structure and the second redistribution structure.

[0089] The foregoing outlines features of several embodiments so that those skilled in the art may better understand the aspects of the present disclosure. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions, and alterations herein without departing from the spirit and scope of the present disclosure.

Claims

1. A semiconductor package, comprising: a first component comprising: a first redistribution structure; a through via disposed over the first redistribution structure; a first die attached to a first side of the first redistribution structure; and a second die attached to a second side of the first redistribution structure, an active side of the first die facing the first redistribution structure; a second component comprising: a second redistribution structure; a connector disposed on a first side of the second redistribution structure, the connector coupling the through via to the second redistribution structure; and a third die attached to the first side of the second redistribution structure, an active side of the second die facing the second redistribution structure; and a fourth die attached to a second side of the second redistribution structure; and an encapsulant layer disposed between the first redistribution structure and the second redistribution structure, the

encapsulant layer being continuous and in contact with the first die, the second die, the through via, and the connector.

2. The semiconductor package of claim 1, wherein in a plan view a portion of the second die overlaps with a portion of the third die.

3. The semiconductor package of claim 2, wherein an adhesive layer directly interposes the second die and the third die.

4. The semiconductor package of claim 1, wherein in a plan view the second die is laterally displaced from the third die.

5. The semiconductor package of claim 4, wherein in a side view the second die overlaps with a portion of the third die, and wherein the side view is orthogonal to the plan view.

6. The semiconductor package of claim 1, wherein the encapsulant layer is level with a first sidewall of the first redistribution structure.

7. The semiconductor package of claim 6, wherein the encapsulant layer is disposed along a second sidewall of the second redistribution structure.

8. A semiconductor package, comprising: a first die attached to a first bottom side of a first redistribution structure; a second die attached to a first top side of the first redistribution structure; a second redistribution structure disposed over and electrically connected to the first redistribution structure by a through via and a connector; a third die attached to a second bottom side of the second redistribution structure, the second die and the third die interposing the first redistribution structure and the second redistribution structure; and a fourth die attached to a second top side of the second redistribution structure, in a plan view the fourth die overlapping the first die, the second die, and the third die.

9. The semiconductor package of claim 8, wherein in the plan view the third die overlaps the second die.

10. The semiconductor package of claim 8, wherein in the plan view the third die is laterally displaced from the second die.

11. The semiconductor package of claim 10, wherein the second die comprises a topmost surface being most distal from the first redistribution structure, wherein the third die comprises a bottommost surface being most distal from the second redistribution structure, and wherein the topmost surface of the second die is more proximal than the bottommost surface of the third die to the second redistribution structure.

12. The semiconductor package of claim 8, further comprising an encapsulant disposed between the first redistribution structure and the second redistribution structure, wherein the encapsulant is continuous and physically contacts the first redistribution structure, the second redistribution structure, the second die, the third die, the through via, and the connector.

13. The semiconductor package of claim 12, wherein the encapsulant physically contacts a sidewall of the second redistribution structure, and wherein the encapsulant is level with a sidewall of the first redistribution structure.

14. The semiconductor package of claim 8, further comprising external connectors disposed on the first bottom side of the first redistribution structure.

15. A semiconductor package, comprising: a first package component comprising: a first redistribution structure comprising conductive features embedded in a plurality of dielectric layers; a through via over the first redistribution structure, the through via extending through a topmost dielectric layer of the plurality of dielectric layer, the through via being electrically connected to the conductive features; and a first die over the first redistribution structure, the first die being laterally displaced from the through via and electrically connected to the conductive features; a second package component comprising: a second redistribution structure over the first redistribution structure; a conductive connector coupling the through via to the second redistribution structure; and a second die attached and electrically connected to the second redistribution structure, the second die being laterally displaced from the conductive connector; and

a molding compound disposed between the first redistribution structure and the second redistribution structure, the molding compound being continuously in physical contact with sidewalls of the first die, the second die, the through via, the conductive connector, and the second redistribution structure.

16. The semiconductor package of claim 15, wherein the first die is more proximal than the through via to the second redistribution structure.

17. The semiconductor package of claim 15, wherein the first redistribution structure is a distance from the second redistribution structure, and wherein a sum of a first height of the first die, a second height of the second die, and a thickness of an intervening adhesive layer is substantially the same as the distance.

18. The semiconductor package of claim 15, wherein the second redistribution structure comprises additional conductive features embedded in an Ajinomoto Build-up Film.

19. The semiconductor package of claim 15, wherein the molding compound is in physical contact with an entirety of the sidewall of the second redistribution structure.

20. The semiconductor package of claim 15, wherein the molding compound comprises an epoxy.
