

SEMICONDUCTOR DEVICE AND METHOD OF FORMING INTERCONNECT STRUCTURE OVER SEED LAYER ON CONTACT PAD OF SEMICONDUCTOR DIE WITHOUT UNDERCUTTING SEED LAYER BENEATH INTERCONNECT STRUCTURE

Field of the Invention

The present invention relates in general to semiconductor devices and, more particularly, to a semiconductor device and method of forming an interconnect structure over a seed layer on a contact pad of a semiconductor die without undercutting the seed layer beneath the interconnect structure.

Background of the Invention

Semiconductor devices are commonly found in modern electronic products. Semiconductor devices vary in the number and density of electrical components. Discrete semiconductor devices generally contain one type of electrical component, e.g., light emitting diode (LED), small signal transistor, resistor, capacitor, inductor, and power metal oxide semiconductor field effect transistor (MOSFET). Integrated semiconductor devices typically contain hundreds to millions of electrical components. Examples of integrated semiconductor devices include microcontrollers, microprocessors, charged-coupled devices (CCDs), solar cells, and digital micro-mirror devices (DMDs).

Semiconductor devices perform a wide range of functions such as signal processing, high-speed calculations, transmitting and receiving electromagnetic signals, controlling electronic devices, transforming sunlight to electricity, and creating visual projections for television displays.

Semiconductor devices are found in the fields of entertainment, communications, power conversion, networks, computers, and consumer products. Semiconductor devices are also found in military applications, aviation, automotive, industrial controllers, and office equipment.

Semiconductor devices exploit the electrical properties of semiconductor materials. The atomic structure of semiconductor material allows its electrical conductivity to be manipulated by the application of an electric field or base current or through the process of doping. Doping introduces impurities into the semiconductor material to manipulate and control the conductivity of the semiconductor device.

A semiconductor device contains active and passive electrical structures. Active structures, including bipolar and field effect transistors, control the flow of electrical current. By varying levels of doping and application of an electric field or base current, the transistor either promotes or restricts the flow of electrical current. Passive structures, including resistors, capacitors, and inductors, create a relationship between voltage and current necessary to perform a variety of electrical functions. The passive and active structures are electrically connected to form circuits, which enable the semiconductor device to perform high-speed calculations and other useful functions.

Semiconductor devices are generally manufactured using two complex manufacturing processes, i.e., front-end manufacturing, and back-end manufacturing, each involving potentially hundreds of steps. Front-end manufacturing involves the formation of a plurality of die on the surface of a semiconductor wafer. Each semiconductor die is typically identical and contains circuits formed by electrically

connecting active and passive components. Back-end manufacturing involves singulating individual semiconductor die from the finished wafer and packaging the die to provide structural support and environmental isolation. The term “semiconductor die” as used herein refers to both the singular and plural form of the words, and accordingly, can refer to both a single semiconductor device and multiple semiconductor devices.

One goal of semiconductor manufacturing is to produce smaller semiconductor devices. Smaller devices typically consume less power, have higher performance, and can be produced more efficiently. In addition, smaller semiconductor devices have a smaller footprint, which is desirable for smaller end products. A smaller semiconductor die size can be achieved by improvements in the front-end process resulting in semiconductor die with smaller, higher density active and passive components. Back-end processes may result in semiconductor device packages with a smaller footprint by improvements in electrical interconnection and packaging materials.

A semiconductor die typically contains an interconnect structure for mounting the die to a substrate. For example, the interconnect structure can be a bump or conductive pillar formed over contact pads within an opening in an insulating layer on the semiconductor die. The bump or conductive pillar is bonded to the substrate by reflowing the bump material to provide mechanical and electrical interconnect between the semiconductor die and substrate. Conductive pillars offer the advantage of smaller interconnect pitches and higher interconnect and routing density.

A seed layer is usually necessary between the conductive pillar and contact pad of the semiconductor die for

good adhesion. The seed layer is deposited over the insulating layer and contact pads of the semiconductor die prior to forming the conductive pillars, and then removed from areas outside a footprint the conductive pillar, often by a wet etching process. The wet etch is known to remove a portion of the seed layer under the conductive pillars, i.e., the wet etch undercuts the seed layer beneath the conductive pillars. However, undercutting the seed layer beneath the conductive pillars weakens the adhesion between the conductive pillars and contact pads of the semiconductor die, leading to joint cracking and manufacturing reliability problems. The smaller interconnect pitch increases the occurrence of seed layer undercutting due to an inability to precisely control the wet etch rate. In addition, the conductive pillars are formed up to an edge of the insulating layer over the semiconductor die. A high current density exists around the base of the conductive pillars adjacent to the insulating layer over the semiconductor die, which increases interconnect resistance.

Summary of the Invention

A need exists to form an interconnect structure, such as a conductive pillar or pad, over a seed layer on a contact pad of a semiconductor die without undercutting the seed layer beneath the interconnect structure. Accordingly, in one embodiment, the present invention is a method of making a semiconductor device comprising the steps of providing a semiconductor wafer, forming a first conductive layer over the semiconductor wafer, forming a first insulating layer over the semiconductor wafer with a first opening in the first insulating layer disposed over the first conductive layer, forming a second

conductive layer over the first insulating layer and into the first opening over the first conductive layer, forming a conductive pillar over the first and second conductive layers, and removing a portion of second conductive layer over the first insulating layer outside the first opening in the first insulating layer while leaving the second conductive layer under the conductive pillar. The conductive pillar has a width less than a width of the first opening in the first insulating layer.

In another embodiment, the present invention is a method of making a semiconductor device comprising the steps of providing a semiconductor wafer, forming a first conductive layer over the semiconductor wafer, forming a first insulating layer over the semiconductor wafer with a first opening in the first insulating layer disposed over the first conductive layer, forming a second conductive layer over the first insulating layer and into the first opening over the first conductive layer, forming an interconnect structure over the first and second conductive layers, and removing a portion of second conductive layer over the first insulating layer outside the first opening in the first insulating layer. The interconnect structure has a width less than a width of the first opening in the first insulating layer.

In another embodiment, the present invention is a method of making a semiconductor device comprising the steps of providing a semiconductor die, forming a first insulating layer over the semiconductor die with a first opening in the first insulating layer, forming a first conductive layer over the first insulating layer and into the first opening in the first insulating layer, and forming an interconnect structure over the first conductive layer. The interconnect structure has a width less than a width of the first opening in the first insulating

layer.

In another embodiment, the present invention is a semiconductor device comprising a semiconductor die and first conductive layer formed over the semiconductor die. A first insulating layer is formed over the semiconductor die with a first opening in the first insulating layer disposed over the first conductive layer. A second conductive layer is formed over the first insulating layer and into the first opening over the first conductive layer. An interconnect structure is formed over the first and second conductive layers. The interconnect structure has a width less than a width of the first opening in the first insulating

Brief Description of the Drawings

FIG. 1 illustrates a PCB with different types of packages mounted to its surface;

FIGs. 2a-2c illustrate further detail of the representative semiconductor packages mounted to the PCB;

FIGs. 3a-3m illustrate a process of forming an interconnect structure over a seed layer on a contact pad of a semiconductor die without undercutting the seed layer beneath the interconnect structure;

FIG. 4 illustrates a semiconductor die having an interconnect structure formed over a seed layer on a contact pad of a semiconductor die;

FIG. 5 illustrates a semiconductor die having a conductive pad formed over a seed layer on a contact pad of a semiconductor die;

FIGs. 6a-6g illustrate a process of forming an interconnect structure over a seed layer on a contact pad of a

semiconductor die without undercutting the seed layer beneath the interconnect structure;

FIG. 7 illustrates a semiconductor die having the stacked conductive pads formed over a seed layer on a contact pad of a semiconductor die;

FIGs. 8a-8g illustrate another process of forming an interconnect structure over a seed layer on a contact pad of a semiconductor die without undercutting the seed layer beneath the interconnect structure; and

FIG. 9 illustrates a semiconductor die having the stacked conductive pads formed over a seed layer on a contact pad of a semiconductor die.

Detailed Description of the Drawings

The present invention is described in one or more embodiments in the following description with reference to the figures, in which like numerals represent the same or similar elements. While the invention is described in terms of the best mode for achieving the invention's objectives, it will be appreciated by those skilled in the art that it is intended to cover alternatives, modifications, and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims and their equivalents as supported by the following disclosure and drawings.

Semiconductor devices are generally manufactured using two complex manufacturing processes: front-end manufacturing and back-end manufacturing. Front-end manufacturing involves the formation of a plurality of die on the surface of a semiconductor wafer. Each die on the wafer contains active and passive electrical components, which are electrically connected

to form functional electrical circuits. Active electrical components, such as transistors and diodes, have the ability to control the flow of electrical current. Passive electrical components, such as capacitors, inductors, resistors, and transformers, create a relationship between voltage and current necessary to perform electrical circuit functions.

Passive and active components are formed over the surface of the semiconductor wafer by a series of process steps including doping, deposition, photolithography, etching, and planarization. Doping introduces impurities into the semiconductor material by techniques such as ion implantation or thermal diffusion. The doping process modifies the electrical conductivity of semiconductor material in active devices, transforming the semiconductor material into an insulator, conductor, or dynamically changing the semiconductor material conductivity in response to an electric field or base current. Transistors contain regions of varying types and degrees of doping arranged as necessary to enable the transistor to promote or restrict the flow of electrical current upon the application of the electric field or base current.

Active and passive components are formed by layers of materials with different electrical properties. The layers can be formed by a variety of deposition techniques determined in part by the type of material being deposited. For example, thin film deposition can involve chemical vapor deposition (CVD), physical vapor deposition (PVD), electrolytic plating, and electroless plating processes. Each layer is generally patterned to form portions of active components, passive components, or electrical connections between components.

The layers can be patterned using photolithography, which involves the deposition of light sensitive material, e.g.,

photoresist, over the layer to be patterned. A pattern is transferred from a photomask to the photoresist using light. In one embodiment, the portion of the photoresist pattern subjected to light is removed using a solvent, exposing portions of the underlying layer to be patterned. In another embodiment, the portion of the photoresist pattern not subjected to light, the negative photoresist, is removed using a solvent, exposing portions of the underlying layer to be patterned. The remainder of the photoresist is removed, leaving behind a patterned layer. Alternatively, some types of materials are patterned by directly depositing the material into the areas or voids formed by a previous deposition/etch process using techniques such as electroless and electrolytic plating.

Depositing a thin film of material over an existing pattern can exaggerate the underlying pattern and create a non-uniformly flat surface. A uniformly flat surface is required to produce smaller and more densely packed active and passive components. Planarization can be used to remove material from the surface of the wafer and produce a uniformly flat surface. Planarization involves polishing the surface of the wafer with a polishing pad. An abrasive material and corrosive chemical are added to the surface of the wafer during polishing. The combined mechanical action of the abrasive and corrosive action of the chemical removes any irregular topography, resulting in a uniformly flat surface.

Back-end manufacturing refers to cutting or singulating the finished wafer into the individual die and then packaging the die for structural support and environmental isolation. To singulate the semiconductor die, the wafer is scored and broken along non-functional regions of the wafer called saw streets or scribes. The wafer is singulated using a

laser cutting tool or saw blade. After singulation, the individual semiconductor die are mounted to a package substrate that includes pins or contact pads for interconnection with other system components. Contact pads formed over the semiconductor die are then connected to contact pads within the package. The electrical connections can be made with solder bumps, stud bumps, conductive paste, or wirebonds. An encapsulant or other molding material is deposited over the package to provide physical support and electrical isolation. The finished package is then inserted into an electrical system and the functionality of the semiconductor device is made available to the other system components.

FIG. 1 illustrates electronic device 50 having a chip carrier substrate or printed circuit board (PCB) 52 with a plurality of semiconductor packages mounted on its surface. Electronic device 50 can have one type of semiconductor package, or multiple types of semiconductor packages, depending on the application. The different types of semiconductor packages are shown in FIG. 1 for purposes of illustration.

Electronic device 50 can be a stand-alone system that uses the semiconductor packages to perform one or more electrical functions. Alternatively, electronic device 50 can be a subcomponent of a larger system. For example, electronic device 50 can be part of a cellular phone, personal digital assistant (PDA), digital video camera (DVC), or other electronic communication device. Alternatively, electronic device 50 can be a graphics card, network interface card, or other signal processing card that can be inserted into a computer. The semiconductor package can include microprocessors, memories, application specific integrated circuits (ASIC), logic circuits, analog circuits, RF circuits, discrete devices, or other

semiconductor die or electrical components. Miniaturization and weight reduction are essential for these products to be accepted by the market. The distance between semiconductor devices must be decreased to achieve higher density.

In FIG. 1, PCB 52 provides a general substrate for structural support and electrical interconnect of the semiconductor packages mounted on the PCB. Conductive signal traces 54 are formed over a surface or within layers of PCB 52 using evaporation, electrolytic plating, electroless plating, screen printing, or other suitable metal deposition process. Signal traces 54 provide for electrical communication between each of the semiconductor packages, mounted components, and other external system components. Traces 54 also provide power and ground connections to each of the semiconductor packages.

In some embodiments, a semiconductor device has two packaging levels. First level packaging is a technique for mechanically and electrically attaching the semiconductor die to an intermediate carrier. Second level packaging involves mechanically and electrically attaching the intermediate carrier to the PCB. In other embodiments, a semiconductor device may only have the first level packaging where the die is mechanically and electrically mounted directly to the PCB.

For the purpose of illustration, several types of first level packaging, including bond wire package 56 and flipchip 58, are shown on PCB 52. Additionally, several types of second level packaging, including ball grid array (BGA) 60, bump chip carrier (BCC) 62, dual in-line package (DIP) 64, land grid array (LGA) 66, multi-chip module (MCM) 68, quad flat non-leaded package (QFN) 70, and quad flat package 72, are shown mounted on PCB 52. Depending upon the system requirements, any combination of semiconductor packages, configured with any

combination of first and second level packaging styles, as well as other electronic components, can be connected to PCB 52. In some embodiments, electronic device 50 includes a single attached semiconductor package, while other embodiments call for multiple interconnected packages. By combining one or more semiconductor packages over a single substrate, manufacturers can incorporate pre-made components into electronic devices and systems. Because the semiconductor packages include sophisticated functionality, electronic devices can be manufactured using cheaper components and a streamlined manufacturing process. The resulting devices are less likely to fail and less expensive to manufacture resulting in a lower cost for consumers.

FIGs. 2a-2c show exemplary semiconductor packages. FIG. 2a illustrates further detail of DIP 64 mounted on PCB 52. Semiconductor die 74 includes an active region containing analog or digital circuits implemented as active devices, passive devices, conductive layers, and dielectric layers formed within the die and are electrically interconnected according to the electrical design of the die. For example, the circuit can include one or more transistors, diodes, inductors, capacitors, resistors, and other circuit elements formed within the active region of semiconductor die 74. Contact pads 76 are one or more layers of conductive material, such as aluminum (Al), copper (Cu), tin (Sn), nickel (Ni), gold (Au), or silver (Ag), and are electrically connected to the circuit elements formed within semiconductor die 74. During assembly of DIP 64, semiconductor die 74 is mounted to an intermediate carrier 78 using a gold-silicon eutectic layer or adhesive material such as thermal epoxy or epoxy resin. The package body includes an insulative packaging material such as polymer or ceramic. Conductor leads

80 and bond wires 82 provide electrical interconnect between semiconductor die 74 and PCB 52. Encapsulant 84 is deposited over the package for environmental protection by preventing moisture and particles from entering the package and contaminating semiconductor die 74 or bond wires 82.

FIG. 2b illustrates further detail of BCC 62 mounted on PCB 52. Semiconductor die 88 is mounted to carrier 90 using an underfill or epoxy-resin adhesive material 92. Bond wires 94 provide first level packaging interconnect between contact pads 96 and 98. Molding compound or encapsulant 100 is deposited over semiconductor die 88 and bond wires 94 to provide physical support and electrical isolation for the device. Contact pads 102 are formed over a surface of PCB 52 using a suitable metal deposition process such as electrolytic plating or electroless plating to prevent oxidation. Contact pads 102 are electrically connected to one or more conductive signal traces 54 in PCB 52. Bumps 104 are formed between contact pads 98 of BCC 62 and contact pads 102 of PCB 52.

In FIG. 2c, semiconductor die 58 is mounted face down to intermediate carrier 106 with a flipchip style first level packaging. Active region 108 of semiconductor die 58 contains analog or digital circuits implemented as active devices, passive devices, conductive layers, and dielectric layers formed according to the electrical design of the die. For example, the circuit can include one or more transistors, diodes, inductors, capacitors, resistors, and other circuit elements within active region 108. Semiconductor die 58 is electrically and mechanically connected to carrier 106 through bumps 110.

BGA 60 is electrically and mechanically connected to PCB 52 with a BGA style second level packaging using bumps 112. Semiconductor die 58 is electrically connected to conductive

signal traces 54 in PCB 52 through bumps 110, signal lines 114, and bumps 112. A molding compound or encapsulant 116 is deposited over semiconductor die 58 and carrier 106 to provide physical support and electrical isolation for the device. The flipchip semiconductor device provides a short electrical conduction path from the active devices on semiconductor die 58 to conduction tracks on PCB 52 in order to reduce signal propagation distance, lower capacitance, and improve overall circuit performance. In another embodiment, the semiconductor die 58 can be mechanically and electrically connected directly to PCB 52 using flipchip style first level packaging without intermediate carrier 106.

FIGs. 3a-3m illustrate, in relation to FIGs. 1 and 2a-2c, a process of forming an interconnect structure over a seed layer on a contact pad of a semiconductor die without undercutting the seed layer beneath the interconnect structure. FIG. 3a shows a semiconductor wafer 120 with a base substrate material 122, such as silicon, germanium, gallium arsenide, indium phosphide, or silicon carbide, for structural support. A plurality of semiconductor die or components 124 is formed on wafer 120 separated by a non-active, inter-die wafer area or saw street 126 as described above. Saw street 126 provides cutting areas to singulate semiconductor wafer 120 into individual semiconductor die 124.

FIG. 3b shows a cross-sectional view of a portion of semiconductor wafer 120. Each semiconductor die 124 has a back surface 128 and active surface 130 containing analog or digital circuits implemented as active devices, passive devices, conductive layers, and dielectric layers formed within the die and electrically interconnected according to the electrical design and function of the die. For example, the circuit may

include one or more transistors, diodes, and other circuit elements formed within active surface 130 to implement analog circuits or digital circuits, such as digital signal processor (DSP), ASIC, memory, or other signal processing circuit. Semiconductor die 124 may also contain integrated passive devices (IPDs), such as inductors, capacitors, and resistors, for RF signal processing. In one embodiment, semiconductor die 124 is a flipchip type device.

An insulating or dielectric layer 132 is formed over active surface 130 using PVD, CVD, printing, spin coating, spray coating, sintering or thermal oxidation. The insulating layer 132 contains one or more layers of silicon dioxide (SiO_2), silicon nitride (Si_3N_4), silicon oxynitride (SiON), tantalum pentoxide (Ta_2O_5), aluminum oxide (Al_2O_3), benzocyclobutene (BCB), polyimide (PI), polybenzoxazoles (PBO), or other suitable dielectric material.

In FIG. 3c, an electrically conductive layer 134 is formed over insulating layer 132 using PVD, CVD, electrolytic plating, electroless plating process, or other suitable metal deposition process. Conductive layer 134 can be one or more layers of Al, Cu, Sn, Ni, Au, Ag, or other suitable electrically conductive material. Conductive layer 134 operates as contact pads electrically connected to the circuits on active surface 130, e.g., through conductive vias formed through insulating layer 132.

In FIG. 3d, an insulating or passivation layer 136 is formed over insulating layer 132 and conductive layer 134 using PVD, CVD, printing, spin coating, spray coating, sintering or thermal oxidation. The insulating layer 136 contains one or more layers of SiO_2 , Si_3N_4 , SiON , Ta_2O_5 , Al_2O_3 , or other material having similar insulating and structural properties. A

portion of insulating layer 136 is removed by an etching process through a photoresist layer (not shown) to form openings 137 disposed over and exposing conductive layer 134. In one embodiment, the width of openings 137 in insulating layer 136, and correspondingly a width of the exposed conductive layer 134, is 50 micrometers (μm).

In FIG. 3e, an electrically conductive layer 138 is conformally applied over conductive layer 134 and insulating layer 136 using PVD, CVD, electrolytic plating, electroless plating process, or other suitable metal deposition process. Conductive layer 138 can be one or more layers of Al, Cu, titanium (Ti), Sn, Ni, Au, Ag, or other suitable electrically conductive material. Conductive layer 138 follows the contour of conductive layer 134 and insulating layer 136. In one embodiment, conductive layer 138 is a seed layer containing multiple layers of Ti/Cu or Ti/Au and electrically connected to conductive layer 134.

In FIG. 3f, a thick insulating layer 140 is formed over insulating layer 136 and conductive layer 138. In one embodiment, insulating layer 140 is a dry-film material with a PET support film. The insulating layer 140 may have a thickness of 120 μm . A portion of insulating layer 140 is removed by subjecting irradiated DFR material to a developer which selectively dissolves non-irradiated portions of the DFR material to create patterned openings 142 in insulating layer 140 disposed over conductive layers 134 and 138, while leaving the irradiated portions of the photoresist material intact. In one embodiment, patterned openings 142 in insulating layer 140 have a width of 40 μm , which is less than the width of openings 137. Accordingly, insulating layer 140 partially overhangs openings 137.

In another embodiment, insulating layer 140 can contain one or more layers of SiO₂, Si₃N₄, SiON, Ta₂O₅, Al₂O₃, solder resist, or other photo-sensitive material formed by PVD, CVD, printing, spin coating, spray coating, sintering or thermal oxidation. A portion of insulating layer 140 is removed by patterning, exposure to UV light, and developing to form openings 142 and expose a portion of conductive layer 138 disposed over conductive layer 134 within patterned openings 137. Again, the width of patterned openings 142 in insulating layer 140 is less than the width of openings 137 so that insulating layer 140 partially overhangs openings 137.

Alternatively, patterned openings 142 can be formed by laser direct ablation (LDA) using laser 144 to remove portions of insulating layer 140 and expose a portion of conductive layer 138 disposed over conductive layer 134 within patterned openings 137 in applications requiring finer interconnect dimensions, as shown in FIG. 3g.

In FIG. 3h, an electrically conductive material is deposited over conductive layer 138 within patterned openings 142 in insulating layer 140 using a metal deposition process such as PVD, CVD, sputtering, electrolytic plating, and electroless plating. The conductive material can be multiple layers of Al, palladium (Pd), indium (In), Cu, Sn, Ni, Au, or Ag. The conductive material partially fills patterned openings 142 in insulating layer 140 to form cylindrical conductive pillars 146 as an interconnect structure over conductive layer 138 of semiconductor die 124. Due to the narrower patterned openings 142 and overhanging insulating layer 140 over openings 137, the conductive material also covers the portions of conductive layer 138 within openings 137 outside of the sidewalls of openings 142, i.e., outside the vertical footprint

of cylindrical conductive pillars 146. In one embodiment, conductive pillars 146 have a height of 40-50 μm . Conductive pillars 146 are electrically connected to conductive layers 134 and 138.

FIG. 3i shows a top view of insulating layer 140 and cylindrical conductive pillars 146 formed within patterned openings 142 in the insulating layer.

In FIG. 3j, an electrically conductive bump material 148 is deposited over surface 150 of conductive pillars 146 within patterned openings 142 in insulating layer 140 using an evaporation, electrolytic plating, electroless plating, ball drop, or screen printing process. Bump material 148 can be Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, solder, and combinations thereof, with an optional flux solution. For example, bump material 148 can be eutectic Sn/Pb, high-lead solder, or lead-free solder. Bump material 148 is bonded to surface 150 of conductive pillars 146 using a suitable attachment or bonding process. In one embodiment, bump material 148 is reflowed by heating the material above its melting point to form bump caps 152, as shown in FIG. 3k. In some applications, bump caps 152 are reflowed a second time to improve electrical contact to conductive pillars 146. Bump caps 152 can also be compression bonded to conductive pillars 146. Conductive pillars 146 and bump caps 152 represent one type of interconnect structure that can be formed over conductive layers 134 and 138.

In FIG. 3l, insulating layer 140 is removed, leaving cylindrical conductive pillars 146 with bump caps 152 disposed over conductive layers 134 and 138. In FIG. 3m, the portion of conductive layer 138 over insulating layer 136, i.e., outside openings 137, is removed by a wet etching process. Due to the conductive material covering the portions of conductive layer

138 within openings 137 outside of the footprint of cylindrical conductive pillars 146, the wet etching process does not remove conductive layer 138 proximate to conductive pillars 146. That is, the wet etching process does not undercut conductive layer 138 beneath conductive pillars 146. The etch stop of conductive layer 138 is controlled in a manner to occur at the edge of insulating layer 136, i.e., up to the end of openings 137. Since the width of patterned openings 142 in insulating layer 140 is less than the width of openings 137 in insulating layer 136, the width of cylindrical conductive pillars 146 is also less than the width of conductive layer 138 within openings 137 of insulating layer 136. Semiconductor wafer 120 is singulated through saw street 126 using a saw blade or laser cutting tool 154 into individual semiconductor die 124.

FIG. 4 shows semiconductor die 124 with cylindrical conductive pillars 146 and bump caps 152 formed over conductive layers 134 and 138. Conductive pillars 146 have a fine pitch for high density interconnect. In particular, the width of openings 137 in insulating layer 136 and, correspondingly the width of conductive layers 134 and 138 within the openings in the insulating layer, is greater than the width of cylindrical conductive pillars 146. The wider conductive layers 134 and 138 and conductive material within openings 137 in insulating layer 136 decrease current density around the base of conductive pillars 146. Due to the conductive material covering the portions of conductive layer 138 within openings 137 outside of the footprint of conductive pillars 146, the wet etching process does not remove conductive layer 138 proximate to conductive pillars 146. By avoiding the undercut of conductive layer 138 beneath conductive pillars 146, the adhesion between conductive pillars 146 and conductive layer 138 is maintained which

increases joint strength. The narrower conductive pillars 146 reduce stress on insulating layer 136 which reduces cracking of insulating layer 136 and increases manufacturing reliability.

FIG. 5 shows semiconductor die 124 with conductive pads 156 formed over conductive layers 134 and 138, similar to FIGs. 3a-3l. Conductive pads 156 have a fine pitch for high density interconnect. In particular, the width of openings 137 in insulating layer 136 and, correspondingly the width of conductive layers 134 and 138 and conductive material within the openings in the insulating layer, is greater than the width of conductive pads 156. The wider conductive layers 134 and 138 and conductive material within openings 137 in insulating layer 136 decrease current density around the base of conductive pads 156. Due to the conductive material covering the portions of conductive layer 138 within openings 137 outside of the footprint of conductive pads 156, the wet etching process does not remove conductive layer 138 proximate to conductive pads 156. By avoiding the undercut of conductive layer 138 beneath conductive pads 156, the adhesion between conductive pads 156 and conductive layer 138 is maintained which increases joint strength. The narrower conductive pads 156 reduce stress on insulating layer 136 which reduces cracking of insulating layer 136 and increases manufacturing reliability.

FIGs. 6a-6g illustrate, in relation to FIGs. 1 and 2a-2c, a process of forming stacked conductive pads over a seed layer on a contact pad of a semiconductor die without undercutting the seed layer beneath the stacked conductive pads. Continuing from FIG. 3f, an electrically conductive material is deposited within patterned openings 142 in insulating layer 140 disposed over conductive layer 134 and 138 using a metal deposition process such as PVD, CVD, sputtering, electrolytic

plating, and electroless plating, as shown in FIG. 6a. The conductive material can be multiple layers of Al, Pd, In, Cu, Sn, Ni, Au, or Ag. The conductive material partially fills patterned openings 142 in insulating layer 140 to form conductive pads 160. Due to the narrower patterned openings 142 and overhanging insulating layer 140 over openings 137, the conductive material also covers the portions of conductive layer 138 within openings 137 outside of the sidewalls of openings 142. Conductive pads 160 are electrically connected to conductive layers 134 and 138.

In FIG. 6b, a protective masking layer 162 with patterned openings 164 is formed within patterned openings 142 in insulating layer 140 over surface 166 of conductive pads 160. The patterned openings 164 in protective masking layer 162 have a width less than a width of patterned openings 142 in insulating layer 140.

In FIG. 6c, an electrically conductive material is deposited over surface 166 of conductive pads 160 within patterned openings 164 in protective masking layer 162 using a metal deposition process such as PVD, CVD, sputtering, electrolytic plating, and electroless plating. The conductive material can be multiple layers of Al, Pd, Cu, Sn, Ni, Au, or Ag. The conductive material fills openings 164 in protective masking layer 162 to form conductive pads 168 stacked over conductive pads 160. Conductive pads 160 and 168 are electrically connected to conductive layers 134 and 138.

FIG. 6d shows a top view of insulating layer 140 and protective masking layer 162 with conductive pads 168 formed within patterned openings 164 in the protective masking layer.

In FIG. 6e, protective masking layer 162 is removed leaving conductive pads 168 stacked over conductive pads 160.

The smaller patterned openings 164 in masking layer 162 causes a width of conductive pads 168 to be smaller than a width of conductive pads 160.

An electrically conductive bump material is deposited over the stacked conductive pads 160 and 168 within patterned openings 142 in insulating layer 140 using an evaporation, electrolytic plating, electroless plating, ball drop, or screen printing process. The bump material can be Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, solder, and combinations thereof, with an optional flux solution. For example, the bump material can be eutectic Sn/Pb, high-lead solder, or lead-free solder. The bump material is bonded to the stacked conductive pads 160 and 168 using a suitable attachment or bonding process. In one embodiment, the bump material is reflowed by heating the material above its melting point to form bumps 170. In some applications, bumps 170 are reflowed a second time to improve electrical contact to the stacked conductive pads 160 and 168. Bumps 170 can also be compression bonded to the stacked conductive pads 160 and 168. Bumps 170 formed over the stacked conductive pads 160 and 168 represent one type of interconnect structure over conductive layers 134 and 138 of semiconductor die 124. Alternatively, bumps 170 over stacked conductive pads 160 and 168 is an SPOP.

In FIG. 6f, insulating layer 140 is removed, leaving bumps 170 and stacked conductive pads 160 and 168 disposed over conductive layers 134 and 138. In FIG. 6g, the portion of conductive layer 138 over insulating layer 136, i.e., outside openings 137, is removed by a wet etching process. Due to the conductive material covering the portions of conductive layer 138 within openings 137, the wet etching process does not remove conductive layer 138 proximate to conductive pads 160. That is, the wet etching process does not undercut conductive layer 138

beneath conductive pads 160 and 168. The etch stop of conductive layer 138 is controlled to occur at the edge of insulating layer 136, i.e., up to the end of openings 137. Semiconductor wafer 120 is singulated through saw street 126 using a saw blade or laser cutting tool 172 into individual semiconductor die 124.

FIG. 7 shows semiconductor die 124 with bumps 170 and stacked conductive pads 160 and 168 formed over conductive layers 134 and 138. The stacked conductive pads 160 and 168 have a fine pitch for high density interconnect. The wider conductive layers 134 and 138 and conductive material within openings 137 in insulating layer 136 decrease current density around the base of the stacked conductive pads 160 and 168. Due to the conductive material covering the portions of conductive layer 138 within openings 137, the wet etching process does not remove conductive layer 138 proximate to the stacked conductive pads 160 and 168. By avoiding the undercut of conductive layer 138 beneath the stacked conductive pads 160 and 168, the adhesion between conductive pads 160 and conductive layer 138 is maintained which increases joint strength. The narrower conductive pads 160 reduce stress on insulating layer 136 which reduces cracking of insulating layer 136 and increases manufacturing reliability.

FIGs. 8a-8g illustrate, in relation to FIGs. 1 and 2a-2c, another process of forming stacked conductive pads over a seed layer on a contact pad of a semiconductor die without undercutting the seed layer beneath the stacked conductive pads. Continuing from FIG. 3f, an electrically conductive material is deposited within patterned openings 142 in insulating layer 140 disposed over conductive layer 134 and 138 using a metal deposition process such as PVD, CVD, sputtering, electrolytic

plating, and electroless plating, as shown in FIG. 8a. The conductive material can be multiple layers of Al, Pd, In, Cu, Sn, Ni, Au, or Ag. The conductive material partially fills patterned openings 142 in insulating layer 140 to form conductive pads 180. Due to the narrower patterned openings 142 and overhanging insulating layer 140 over openings 137, the conductive material also covers the portions of conductive layer 138 within openings 137 outside of the sidewalls of openings 142. Conductive pads 180 are electrically connected to conductive layers 134 and 138.

In FIG. 8b, a protective masking layer 182 with patterned openings 184 is formed within patterned openings 142 in insulating layer 140 over surface 186 of conductive pads 180. The patterned openings 184 in protective masking layer 182 have a width less than a width of patterned openings 142 in insulating layer 140.

In FIG. 8c, an electrically conductive material is deposited over surface 186 of conductive pads 180 within patterned openings 184 in protective masking layer 182 using a metal deposition process such as PVD, CVD, sputtering, electrolytic plating, and electroless plating. The conductive material can be multiple layers of Al, Pd, Cu, Sn, Ni, Au, or Ag. The conductive material fills openings 184 in protective masking layer 182 to form conductive pads 188 stacked over conductive pads 180. Conductive pads 180 and 188 are electrically connected to conductive layers 134 and 138.

FIG. 8d shows a top view of insulating layer 140 and protective masking layer 182 with conductive pads 188 formed within patterned openings 184 in the protective masking layer.

In FIG. 8e, protective masking layer 182 is removed leaving conductive pads 188 stacked over conductive pads 180.

The smaller patterned openings 184 in masking layer 182 cause a width of conductive pads 188 to be smaller than a width of conductive pads 180.

An electrically conductive bump material is deposited over the stacked conductive pads 180 and 188 within patterned openings 142 in insulating layer 140 using an evaporation, electrolytic plating, electroless plating, ball drop, or screen printing process. The bump material can be Al, Sn, Ni, Au, Ag, Pb, Bi, Cu, solder, and combinations thereof, with an optional flux solution. For example, the bump material can be eutectic Sn/Pb, high-lead solder, or lead-free solder. The bump material is bonded to the stacked conductive pads 180 and 188 using a suitable attachment or bonding process. In one embodiment, the bump material is reflowed by heating the material above its melting point to form bumps 190. In some applications, bumps 190 are reflowed a second time to improve electrical contact to the stacked conductive pads 180 and 188. Bumps 190 can also be compression bonded to the stacked conductive pads 180 and 188. Bumps 190 formed over the stacked conductive pads 180 and 188 represent one type of interconnect structure over conductive layers 134 and 138 of semiconductor die 124. Alternatively, bumps 190 over stacked conductive pads 180 and 188 is an SPOP.

In FIG. 8f, insulating layer 140 is removed, leaving bumps 190 and stacked conductive pads 180 and 188 disposed over conductive layers 134 and 138. In FIG. 8g, the portion of conductive layer 138 over insulating layer 136, i.e., outside openings 137, is removed by a wet etching process. Due to the conductive material covering the portions of conductive layer 138 within openings 137, the wet etching process does not remove conductive layer 138 proximate to conductive pads 180 and 188. That is, the wet etching process does not undercut conductive

layer 138 beneath conductive pads 180 and 188. The etch stop of conductive layer 138 is controlled to occur at the edge of insulating layer 136, i.e., up to the end of openings 137. Semiconductor wafer 120 is singulated through saw street 126 using a saw blade or laser cutting tool 192 into individual semiconductor die 124.

FIG. 9 shows semiconductor die 124 with bumps 190 and stacked conductive pads 180 and 188 formed over conductive layers 134 and 138. The stacked conductive pads 180 and 188 have a fine pitch for high density interconnect. The wider conductive layers 134 and 138 and conductive material within openings 137 in insulating layer 136 decrease current density around the base of the stacked conductive pads 160 and 168. Due to the conductive material covering the portions of conductive layer 138 within openings 137, the wet etching process does not remove conductive layer 138 proximate to the stacked conductive pads 180 and 188. By avoiding the undercut of conductive layer 138 beneath the stacked conductive pads 180 and 188, the adhesion between conductive pads 180 and conductive layer 138 is maintained which increases joint strength. The narrower conductive pads 180 reduce stress on insulating layer 136 which reduces cracking of insulating layer 136 and increases manufacturing reliability.

While one or more embodiments of the present invention have been illustrated in detail, the skilled artisan will appreciate that modifications and adaptations to those embodiments may be made without departing from the scope of the present invention as set forth in the following claims.

Claims

What is claimed:

1. A method of making a semiconductor device, comprising:
providing a substrate;
forming a first conductive layer over the substrate;
forming a first insulating layer over the substrate
including an opening in the first insulating layer disposed over
the first conductive layer;
forming a second conductive layer over the first insulating
layer and into the opening in the first insulating layer; and
forming a conductive pillar including a first region of the
conductive pillar disposed within and terminating at the opening
in the first insulating layer and extending outside a footprint
of a second region of the conductive pillar disposed over the
first region.
2. The method of claim 1, further including forming a bump
material over the conductive pillar.
3. The method of claim 1, further including forming a second
insulating layer over the substrate prior to forming the first
conductive layer.
4. The method of claim 1, wherein forming the conductive pillar
includes:
forming a second insulating layer over the first insulating
layer with an opening in the second insulating layer disposed
over the first and second conductive layers, the opening in the

second insulating layer including a width less than a width of the opening in the first insulating layer;

depositing a conductive material into the opening of the second insulating layer to form the conductive pillar; and

removing the second insulating layer to leave the conductive pillar with a width less than the width of the opening in the first insulating layer.

5. The method of claim 4, further including forming the opening in the second insulating layer by laser direct ablation to expose the second conductive layer.

6. A method of making a semiconductor device, comprising:
providing a substrate;

forming a conductive layer over the substrate;

forming a first insulating layer over the substrate including an opening in the first insulating layer disposed over the conductive layer; and

forming an interconnect structure including a first region of the interconnect structure disposed within and terminating at the opening in the first insulating layer and extending outside a footprint of a second region of the interconnect structure disposed over the first region.

7. The method of claim 6, wherein the interconnect structure includes a conductive pillar or conductive pad.

8. The method of claim 6, further including forming a second insulating layer over the substrate prior to forming the conductive layer.

9. The method of claim 6, wherein forming the interconnect structure includes:

forming a second insulating layer over the first insulating layer with an opening in the second insulating layer disposed over the opening in the first insulating layer, the opening in the second insulating layer including a width less than a width of the opening in the first insulating layer;

depositing a conductive material into the opening of the second insulating layer to form the interconnect structure; and

removing the second insulating layer to leave the interconnect structure with a width less than the width of the opening in the first insulating layer.

10. The method of claim 6, wherein forming the interconnect structure includes:

forming a second insulating layer over the first insulating layer with an opening in the second insulating layer disposed over the opening in the first insulating layer, the opening in the second insulating layer including a width less than a width of the opening in the first insulating layer; and

depositing a first conductive material into the opening in the second insulating layer to form a first conductive pad.

11. The method of claim 7, further including forming a bump material over the conductive pillar or conductive pad.

12. The method of claim 9, further including forming the opening in the second insulating layer by laser direct ablation.

13. The method of claim 10, wherein forming the interconnect structure further includes:

forming a masking layer over the first conductive material with an opening in the masking layer disposed over the first conductive pad, the opening in the masking layer including a width less than the width of the opening in the second insulating layer;

depositing a second conductive material into the opening in the masking layer to form a second conductive pad stacked over the first conductive pad;

removing the masking layer;

depositing a bump material over the first and second conductive pads; and

removing the second insulating layer to leave the interconnect structure.

14. A method of making a semiconductor device, comprising:

providing a substrate;

forming a first insulating layer over the substrate including an opening in the first insulating layer disposed over the substrate;

forming a first conductive layer over the first insulating layer and into the opening in the first insulating layer; and

forming an interconnect structure with a first portion of the interconnect structure disposed within the opening in the first insulating layer to a surface of the first insulating layer and a second portion of the interconnect structure disposed over the first portion of the interconnect structure including a width less than the opening in the first insulating layer.

15. The method of claim 14, further including removing a portion of first conductive layer over the first insulating layer outside the opening in the first insulating layer.

16. The method of claim 14, further including forming a second conductive layer over the substrate prior to forming the first insulating layer, the opening in the first insulating layer being disposed over the second conductive layer.

17. The method of claim 14, wherein the interconnect structure includes a conductive pillar or conductive pad.

18. The method of claim 14, wherein forming the interconnect structure includes:

forming a second insulating layer over the first insulating layer with an opening in the second insulating layer disposed over the first conductive layer, the opening in the second insulating layer including a width less than a width of the opening in the first insulating layer;

depositing a conductive material into the opening in the second insulating layer to form the interconnect structure; and

removing the second insulating layer to leave the interconnect structure with the width less than the width of the opening in the first insulating layer.

19. The method of claim 14, wherein forming the interconnect structure includes:

forming a second insulating layer over the first insulating layer with an opening in the second insulating layer disposed over the first conductive layer, the opening in the second

insulating layer including a width less than a width of the opening in the first insulating layer; and

depositing a first conductive material into the opening in the second insulating layer to form a first conductive pad.

20. The method of claim 19, wherein forming the interconnect structure further includes:

forming a masking layer over the first conductive material with an opening in the masking layer disposed over the first conductive pad, the opening in the masking layer including a width less than the width of the opening in the second insulating layer;

depositing a second conductive material into the opening in the masking layer to form a second conductive pad stacked over the first conductive pad;

removing the masking layer;

depositing a bump material over the first and second conductive pads; and

removing the second insulating layer to leave the interconnect structure with the width less than the width of the opening in the first insulating layer.

21. A method of making a semiconductor device, comprising:

providing a substrate including a first insulating layer disposed over a surface of the substrate;

forming a first conductive layer in an opening of the first insulating layer; and

forming an interconnect structure including a first region of the interconnect structure disposed within and terminating at the opening of the first insulating layer to extend outside a

footprint of a second region of the interconnect structure disposed over the first region.

22. The method of claim 21, further including forming a second insulating layer over the first insulating layer.

23. The method of claim 21, further including forming a second conductive layer over the substrate prior to forming the first insulating layer.

24. The method of claim 21, wherein the interconnect structure includes a conductive pillar or conductive pad.

25. The method of claim 21, further including forming a bump material over the interconnect structure.