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SEMICONDUCTOR PACKAGE

Abstract

A semiconductor package including a first semiconductor chip including a logic structure and a second semiconductor chip bonded to the first semiconductor chip may be provided. The first semiconductor chip may include signal lines on a first surface of a first semiconductor substrate and connected to the logic structure, a power delivery network on a second surface of the first semiconductor substrate, the second surface being opposite to the first surface, and penetration vias penetrating the first semiconductor substrate and connecting the power delivery network to the logic structure. The second semiconductor chip may include a capacitor layer that is on a second semiconductor substrate and is adjacent to the power delivery network.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This U.S. non-provisional patent application is a continuation of U.S. application Ser. No. 18/508,663, filed on Nov. 14, 2023, which is a continuation of U.S. application Ser. No. 17/369,228, filed on Jul. 7, 2021, now granted as U.S. Pat. No. 11,862,618 on Jul. 7, 2021, which claims priority under 35 U.S.C. § 119 to Korean Patent Application No. 10-2020-0157108, filed on Nov. 20, 2020, in the Korean Intellectual Property Office, the entire contents of each of which are hereby incorporated by reference.

BACKGROUND

[0002] The present disclosure relates to semiconductor packages, and in particular, to semiconductor packages with improved operation characteristics.

[0003] A semiconductor package is configured to easily use a semiconductor chip as a part of an electronic product. In general, the semiconductor package includes a printed circuit board (PCB) and a semiconductor chip, which is mounted on the PCB and is electrically connected to the PCB by bonding wires or bumps. With development of electronics industry, many studies are being conducted to improve reliability of the semiconductor package and to reduce a size of the semiconductor package.

SUMMARY

[0004] An example embodiment of the inventive concepts provides a semiconductor package with improved operation characteristics.

[0005] According to an example embodiment of the inventive concepts, a semiconductor package may include a first semiconductor chip including a logic structure and a second semiconductor chip bonded to the first semiconductor chip. The first semiconductor chip may include signal lines on a first surface of a first semiconductor substrate and connected to the logic structure, a power delivery network on a second surface of the first semiconductor substrate, the second surface being opposite to the first surface, and penetration vias penetrating the first semiconductor substrate and connecting the power delivery network to the logic structure. The second semiconductor chip may include a capacitor layer that is on a second semiconductor substrate and is adjacent to the power delivery network.

[0006] According to an example embodiment of the inventive concepts, a semiconductor package may include a first semiconductor substrate, a second semiconductor substrate, a power delivery network between the first semiconductor substrate and the second semiconductor substrate, and a capacitor layer between the power delivery network and the second semiconductor substrate.

[0007] According to an example embodiment of the inventive concepts, a semiconductor package may include a first semiconductor substrate having a first surface and a second surface opposite to the first surface, active patterns on the first surface of the first semiconductor substrate, active contacts connected to the active patterns, signal lines on the active contacts and connected to the active contacts, buried power rails in the first semiconductor substrate and connected to the active patterns, penetration vias penetrating the first semiconductor substrate and connected to the buried power rails, a power delivery network on the second surface of the first semiconductor substrate, the power delivery network including power lines connected to the penetration vias, first bonding pads connected to the power delivery network, a capacitor layer including power decoupling capacitors on a third surface of a second semiconductor substrate, the third surface facing the power delivery network, and second bonding pads connected to the power decoupling capacitors. The first and second bonding pads may be bonded to each other.

[0008] According to an example embodiment of the inventive concepts, a semiconductor package may include a logic structure on a first semiconductor substrate, a capacitor layer including power decoupling capacitors on a second semiconductor substrate, and a power delivery network connected to the logic structure and the capacitor layer.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Example embodiments will be more clearly understood from the following brief description taken in conjunction with the accompanying drawings. The accompanying drawings represent non-limiting, example embodiments as described herein.

[0010] FIG. 1 is a schematic sectional view illustrating a semiconductor package according to an example embodiment of the inventive concepts.

[0011] FIG. 2 is a layout diagram illustrating a logic structure of a semiconductor package according to an example embodiment of the inventive concepts.

[0012] FIG. 3 is a sectional view illustrating a semiconductor package according to an example embodiment of the inventive concepts.

[0013] FIGS. 4A and 4B are enlarged sectional views illustrating a portion P of FIG. 3.

[0014] FIGS. 5A and 5B are sectional views illustrating a semiconductor package according to an example embodiment of the inventive concepts.

[0015] FIG. 6 is a schematic sectional view illustrating a semiconductor package according to an example embodiment of the inventive concepts.

[0016] FIG. 7 is a sectional view illustrating a semiconductor package according to an example embodiment of the inventive concepts.

[0017] FIG. 8 is a schematic sectional view illustrating a semiconductor package according to an example embodiment of the inventive concepts.

[0018] FIG. 9 is a sectional view illustrating a semiconductor package according to an example embodiment of the inventive concepts.

[0019] FIG. 10 is a sectional view illustrating a semiconductor package module including a semiconductor package, according to an example embodiment of the inventive concepts.

[0020] FIGS. 11 to 15 are sectional views illustrating a method of fabricating a semiconductor package, according to an example embodiment of the inventive concepts.

[0021] FIG. 16 is a sectional view illustrating a method of fabricating a semiconductor package, according to an example embodiment of the inventive concepts.

[0022] FIGS. 17 and 18 are sectional views illustrating a method of fabricating a semiconductor package, according to an example embodiment of the inventive concepts.

[0023] FIGS. 19 to 22 are sectional views illustrating a method of fabricating a semiconductor

package, according to an example embodiment of the inventive concepts.

[0024] It should be noted that these figures are intended to illustrate the general characteristics of methods, structure and/or materials utilized in certain example embodiments and to supplement the written description provided below. These drawings are not, however, to scale and may not precisely reflect the precise structural or performance characteristics of any given example embodiment, and should not be interpreted as defining or limiting the range of values or properties encompassed by example embodiments. For example, the relative thicknesses and positioning of molecules, layers, regions and/or structural elements may be reduced or exaggerated for clarity. The use of similar or identical reference numbers in the various drawings is intended to indicate the presence of a similar or identical element or feature.

DETAILED DESCRIPTION

[0025] Example embodiments of the inventive concepts will now be described more fully with reference to the accompanying drawings, in which some example embodiments are shown.

[0026] FIG. 1 is a schematic sectional view illustrating a semiconductor package according to an example embodiment of the inventive concepts.

[0027] Referring to FIG. 1, a semiconductor package **100** may include a first semiconductor chip **C1** including a logic structure **IC** and a second semiconductor chip **C2** including a power decoupling capacitor.

[0028] The first semiconductor chip **C1** may include a first semiconductor substrate **10**, the logic structure **IC** provided on a first surface **10a** of the first semiconductor substrate **10**, a power delivery network **PDN** or a power distribution network, which is provided on a second surface of the first semiconductor substrate **10** and is connected to the logic structure **IC** through a plurality of penetration vias **TSV**, and first bonding pads **BP1**. The first bonding pads **BP1** may be provided in the uppermost metal layer of the power delivery network **PDN**. The first semiconductor chip **C1** may be a micro electro mechanical systems (MEMS) device, an optoelectronic device, or a logic chip including processors (e.g., a central processing unit (CPU), a graphic processing unit (GPU), a mobile application chip, or a digital signal processor (DSP)). In this disclosure, the terms “uppermost” and “lowermost” may refer to positions relative to a bottom surface of the semiconductor package **100** at which outer connection terminals **150** are attached, or positions relative to the bottom of each of the figures.

[0029] The second semiconductor chip **C2** may include a second semiconductor substrate **20**, a capacitor layer **PDC** provided on the second semiconductor substrate **20**, and second bonding pads **BP2**. The second bonding pads **BP2** may be provided in the uppermost metal layer of the capacitor layer **PDC**.

[0030] The semiconductor package **100** may include chip pads **111**, which are provided on a bottom surface of the second semiconductor chip **C2**, and the outer connection terminals (or alternatively, connection terminals) **150** may be attached to the chip pads.

[0031] The semiconductor package **100** may be a chip-to-chip (C2C) structure, which is formed by fabricating the first semiconductor chip **C1** on a first wafer, fabricating the second semiconductor chip **C2** on a second wafer different from the first wafer, and connecting the first semiconductor chip **C1** to the second semiconductor chip **C2** in a bonding manner.

[0032] In the bonding manner, the first bonding pads **BP1** of the first semiconductor chip **C1** may be electrically connected to the second bonding pads **BP2** of the second semiconductor chip **C2**. For example, in the case where the first and second bonding pads **BP1** and **BP2** are formed of copper (Cu), the bonding manner may be a Cu-to-Cu bonding manner, but in an example embodiment, the first and second bonding pads **BP1** and **BP2** may be formed of aluminum (Al) or tungsten (W).

[0033] In an example embodiment, the first and second semiconductor chips **C1** and **C2** may be connected to each other using connection terminals (not shown) (e.g., conductive bumps, conductive pillars, and solder balls), which are provided between the first and second bonding pads

BP1 and BP2.

[0034] FIG. 2 is a layout diagram illustrating a logic structure of a semiconductor package according to an example embodiment of the inventive concepts. FIG. 3 is a sectional view illustrating a semiconductor package according to an example embodiment of the inventive concepts. FIGS. 4A and 4B are enlarged sectional views illustrating a portion P of FIG. 3.

[0035] Referring to FIGS. 2 and 3, the first semiconductor chip C1 may include the first semiconductor substrate 10, the logic structure IC, and the power delivery network PDN.

[0036] The logic structure IC may include logic devices, which are integrated on a first surface 10a of the first semiconductor substrate 10, and signal lines INC1, which are connected to the logic devices. The logic devices may include at least one of an AND circuit, an OR circuit, a NOR circuit, an inverter circuit, or a latch circuit. Further, the logic devices may include field effect transistors, resistors, or the like.

[0037] For example, the first semiconductor substrate 10 may be a silicon substrate, a germanium substrate, a silicon-germanium substrate, a silicon-on-insulator (SOI) substrate, or germanium-on-insulator (GOI) substrate. As an example, the first semiconductor substrate 10 may be a silicon wafer.

[0038] Buried power rails BPR1, BPR2, and BPR3 may be provided in the first semiconductor substrate 10. The buried power rails BPR1, BPR2, and BPR3 may be extended in a first direction D1 and parallel to each other. In an example embodiment, the buried power rails BPR1, BPR2, and BPR3 may include first, second, and third buried power rails BPR1, BPR2, and BPR3. The first and third buried power rails BPR1 and BPR3 may be interconnection lines, to which a power voltage is applied, and the second buried power rail BPR2 may be an interconnection line, to which a ground voltage is applied.

[0039] The first semiconductor substrate 10 may include a first logic circuit region R1 between the first and second buried power rails BPR1 and BPR2 and a second logic circuit region R2 between the second and third buried power rails BPR2 and BPR3.

[0040] Each of the first and second logic circuit regions R1 and R2 may include first and second active regions NR and PR. As an example, PMOS field effect transistors may be provided on the first active region NR, and NMOS field effect transistors may be provided on the second active region PR. The first and second active regions NR and PR of the first semiconductor substrate 10 may be doped with dopants of different conductivity types.

[0041] A plurality of first active patterns AP1 may be provided in the first active region NR to extend in the first direction D1 and may be spaced apart from each other in a second direction D2 crossing the first direction D1. A plurality of second active patterns AP2 may be provided in the second active region PR to extend in the first direction D1 and may be spaced apart from each other in the second direction D2. The first and second active patterns AP1 and AP2 may be portions of the first semiconductor substrate 10 and may be defined by first trenches, which are formed in the first semiconductor substrate 10. An example, in which three first active patterns AP1 are provided, is illustrated, but the number of the first active patterns AP1 is not limited thereto and is variously changed. This is the same for the second active patterns AP2.

[0042] In an example embodiment, each of the first and second active patterns AP1 and AP2 may include a plurality of channel patterns, which are vertically stacked to be spaced apart from each other. The stacked channel patterns may be vertically overlapped with each other. The channel patterns may be formed of or include at least one of silicon (Si), germanium (Ge), or silicon-germanium (SiGe).

[0043] A device isolation layer 11 may be disposed between the first active patterns AP1 and between the second active patterns AP2. The device isolation layer 11 may separate the first and second active patterns AP1 and AP2 from each other in the second direction D2. The first and second active patterns AP1 and AP2 may include upper portions, which are exposed by the device isolation layer 11. For example, the device isolation layer 11 may have a top surface that is located

at a level lower than top surfaces of the first and second active patterns AP1 and AP2, and the upper portions of the first and second active patterns AP1 and AP2 may protrude above the top surface of the device isolation layer 11.

[0044] Gate structures GS may be extended in the second direction D2 to cross the first and second active patterns AP1 and AP2 of the first and second active regions NR and PR. The gate structures GS may be arranged with a uniform pitch. In other words, the gate structures GS may have substantially the same width and may be spaced apart from each other by a uniform distance in the first direction D1.

[0045] In the case where each of the first and second active patterns AP1 and AP2 includes the channel patterns that are vertically stacked, the gate structure GS may include a gate electrode (not shown), which is provided to surround each of the channel patterns. The gate electrode may be provided to face or cover top, bottom, and opposite side surfaces of each of the channel patterns. In other words, the logic device may be a three-dimensional field-effect transistor (e.g., MBCFET or GAAFET), in which the gate electrode is provided to three-dimensionally surround the channel patterns.

[0046] Furthermore, as shown in FIGS. 2 and 3, first and second active contacts AC1 and AC2 may be provided on the first and second active patterns AP1 and AP2 and at both sides of the gate structures GS. The active contacts AC1 and AC2 may be in direct contact with the first and second active patterns AP1 and AP2 or may be connected to the first and second active patterns AP1 and AP2 through source/drain patterns (not shown). Here, the source/drain patterns may be epitaxial patterns that are formed by a selective epitaxial growth process.

[0047] In an example embodiment, the active contacts AC1 and AC2 may include first active contacts AC1, which are connected to the first, second, and third buried power rails BPR1, BPR2, and BPR3, and second active contacts AC2, which are connected to the signal lines INC1.

[0048] The first, second, and third buried power rails BPR1, BPR2, and BPR3 may be partially buried in the first semiconductor substrate 10. The first, second, and third buried power rails BPR1, BPR2, and BPR3 may be provided in the device isolation layer 11. The first, second, and third buried power rails BPR1, BPR2, and BPR3 may be in direct contact with the first active contacts AC1. The first, second, and third buried power rails BPR1, BPR2, and BPR3 may have top surfaces that are located at a level lower than the top surfaces of the first and second active patterns AP1 and AP2.

[0049] A buried signal line BSI may be provided at the same level as the first, second, and third buried power rails BPR1, BPR2, and BPR3. Input/output signals, which are input through chip pads 111, may be delivered to the signal lines INC1 through the buried signal line BSI and the penetration via TSV.

[0050] A first interlayer insulating layer 13 may be provided to fill spaces between the gate structures GS and between the active contacts AC1 and AC2. The first interlayer insulating layer 13 may be provided to cover the first, second, and third buried power rails BPR1, BPR2, and BPR3 and the buried signal line BSI.

[0051] A second interlayer insulating layer 15 may be disposed on the first interlayer insulating layer 13. The signal lines INC1, which are electrically connected to the logic devices, may be provided on the second interlayer insulating layer 15. The signal lines INC1 may be electrically connected to the gate structures GS or the second active contacts AC2 through a plurality of contact plugs. The signal lines INC1 may include a plurality of metal lines, which are stacked with inter-metal insulating layers IMD1 interposed therebetween.

[0052] A surface insulating layer 120 may be disposed on a second surface 10b of the first semiconductor substrate 10, and the penetration vias TSV may be provided to penetrate the surface insulating layer 120 and the first semiconductor substrate 10 and may be coupled to the first, second, and third buried power rails BPR1, BPR2, and BPR3 and the buried signal line BSI. The penetration vias TSV may have a diameter of about 50 nm to about 150 nm. The penetration vias

TSV may have a vertical length of about 300 nm to about 1 μm . Although not shown, an insulating layer (not shown) may be interposed between side surfaces of the penetration vias TSV and the first semiconductor substrate **10**. The penetration vias TSV may be formed of or include at least one of metallic materials (e.g., W, WN, WC, Ti, TiN, Ta, TaN, Ru, Co, Mn, WN, Ni, or NiB).

[0053] The power delivery network PDN may be provided on the second surface **10b** of the first semiconductor substrate **10**. The power delivery network PDN may include a plurality of power lines INC2, which are stacked with inter-metal insulating layers IMD2 interposed therebetween. The power lines INC2 may be interconnection lines, which are used to deliver a power voltage or a ground voltage. The power lines INC2 may be electrically connected to the first, second, and third buried power rails BPR1, BPR2, and BPR3 through the penetration vias TSV, which are provided to penetrate the first semiconductor substrate **10**. The power lines INC2 may be formed of or include at least one of metallic materials. The first bonding pads BP1 may be provided in the uppermost metal layer of the power delivery network PDN. The first bonding pads BP1 may be electrically connected to the power lines INC2. The first bonding pads BP1 may be formed of or include at least one of, for example, tungsten (W), aluminum (Al), copper (Cu), tungsten nitride (WN), tantalum nitride (TaN), or titanium nitride (TiN).

[0054] The second semiconductor chip C2 may include the capacitor layer PDC, which is integrated on the second semiconductor substrate **20**.

[0055] The second semiconductor substrate **20** may be a semiconductor substrate including silicon, germanium, silicon-germanium, or the like or a compound semiconductor substrate. In an example embodiment, the second semiconductor substrate **20** may be a silicon wafer.

[0056] Referring to FIGS. **3**, **4A**, and **4B**, the capacitor layer PDC may be provided on a front surface of the second semiconductor substrate **20** (e.g., a first surface of the second semiconductor substrate **20** facing the power delivery network PDN), and the chip pads **111** may be provided on a rear surface of the second semiconductor substrate **20** (e.g., a second surface of the second semiconductor substrate **20** opposite to the first surface of the second semiconductor substrate **20**). The outer connection terminals **150** may be attached to the chip pads **111**. The chip pads **111** may be formed of or include at least one of metallic materials (e.g., copper (Cu), nickel (Ni), cobalt (Co), tungsten (W), titanium (Ti), tin (Sn), or alloys thereof).

[0057] The capacitor layer PDC may include lower and upper interconnection lines INCa and INCb and power decoupling capacitors CAP. The lower and upper interconnection lines INCa and INCb may be formed of or include at least one of metallic materials (e.g., copper, tungsten, and/or titanium).

[0058] The power decoupling capacitors CAP may be arranged in rows and columns to form an array. The power decoupling capacitors CAP may include a plurality of capacitors that are connected in parallel to each other.

[0059] For example, referring to FIG. **4A**, the power decoupling capacitor CAP may be provided between a bottom electrode pad BCP and a top electrode pad TCP and may include a plurality of bottom electrodes BE, a capacitor dielectric layer DIL, and a top electrode TE.

[0060] The bottom electrodes BE may have a pillar shape, as shown in FIG. **4A**. The bottom electrodes BE may have top surfaces that are substantially coplanar with each other. The bottom electrodes BE may have a uniform top width.

[0061] The bottom electrodes BE may be arranged in a shape of zigzag or honeycomb on the bottom electrode pad BCP. Because the bottom electrodes BE are arranged in the zigzag or honeycomb shape, it may be easy to increase diameters of the bottom electrodes BE or it may be possible to increase an integration density of the bottom electrodes BE. As another example, the bottom electrodes BE may be spaced apart from each other by a specific distance in two different directions (e.g., first and second directions) and be arranged in a matrix shape.

[0062] The bottom electrodes BE may be connected in common to the bottom electrode pad BCP, and the bottom electrode pad BCP may be connected to the lower interconnection lines INCa

through contact plugs. The lower interconnection lines INCa may be provided on the second semiconductor substrate **20** with an insulating layer **25** interposed therebetween.

[0063] The capacitor dielectric layer DIL may cover outer surfaces of the bottom electrodes BE with a uniform thickness. The capacitor dielectric layer DIL may also cover the bottom electrode pad BCP between the bottom electrodes BE.

[0064] The top electrode TE may be provided on the capacitor dielectric layer DIL to conformally cover the bottom electrodes BE. In an example embodiment, the top electrode TE may be provided on the capacitor dielectric layer DIL to fill a space between the bottom electrodes BE. The top electrode TE may cover an entirety of the bottom electrodes.

[0065] The bottom electrodes BE and the top electrode TE may be formed of or include at least one of high melting point metals (e.g., cobalt, titanium, nickel, tungsten, and molybdenum) and/or metal nitrides (e.g., titanium nitride (TiN), titanium silicon nitride (TiSiN), titanium aluminum nitride (TiAlN), tantalum nitride (TaN), tantalum silicon nitride (TaSiN), tantalum aluminum nitride (TaAlN), and tungsten nitride (WN)).

[0066] The capacitor dielectric layer DIL may be formed of at least one selected from the group consisting of metal oxides (e.g., HfO₂, ZrO₂, Al₂O₃, La₂O₃, Ta₂O₃, and TiO₂) and perovskite dielectric materials (e.g., SrTiO₃(STO), (Ba,Sr)TiO₃(BST), BaTiO₃, PZT, and PLZT) and may have a single-or multi-layered structure.

[0067] The top electrode pad TCP may be disposed on the top electrode TE. The top electrode pad TCP may be provided on an interlayer insulating layer ILD to be in direct contact with portions of the top electrode TE. The top electrode pad TCP may be formed of or include at least on one of conductive materials, which is different from the top electrode TE, or doped semiconductor materials. The top electrode pad TCP may be formed of or include at least one of, for example, doped polysilicon, silicon germanium, and/or metals (e.g., tungsten, copper, aluminum, titanium, and tantalum).

[0068] As another example, referring to FIG. 4B, each of the bottom electrodes BE of the power decoupling capacitor CAP may have a cylindrical shape including a bottom portion and a sidewall portion, which is vertically extended from the bottom portion to define an empty space. Each of the bottom electrodes BE may have a cup shape conformally covering inner surfaces of openings of a mold insulating layer ML. The capacitor dielectric layer DIL and the top electrode TE may be sequentially disposed on the mold insulating layer ML to conformally cover the bottom electrodes BE. The capacitor dielectric layer DIL may be formed to cover inner surfaces of the bottom electrodes BE with a uniform thickness. The top electrode TE may be provided on the capacitor dielectric layer DIL to cover the bottom electrodes BE. Further, the top electrode TE may cover a surface of the capacitor dielectric layer DIL with a uniform thickness. In an example embodiment, the top electrode TE may be provided to define gap regions in the openings of the mold insulating layer ML.

[0069] Referring back to FIG. 3, the power decoupling capacitors CAP may be electrically connected to the chip pads **111** and the second bonding pads BP2 through the lower and upper interconnection lines INCa and INCb.

[0070] The second bonding pads BP2 may be provided in the uppermost metal layer of the capacitor layer PDC. The second bonding pads BP2 may be directly bonded to the first bonding pads BP1 of the first semiconductor chip C1. Further, a surface of an insulating layer IMD3 of the capacitor layer PDC may be directly bonded to a surface of an insulating layer IMD2 of the power delivery network PDN. In other words, the first and second semiconductor chips C1 and C2 may be bonded to have a hybrid bonding structure. The hybrid bonding structure may mean a bonding structure, in which two materials of the same kind are fused at an interface therebetween.

[0071] FIGS. 5A and 5B are sectional views illustrating a semiconductor package according to an example embodiment of the inventive concepts.

[0072] According to the example embodiment shown in FIG. 5A, the semiconductor package **100** may include the first and second semiconductor chips **C1** and **C2**, connection terminals **30** therebetween, and a mold layer **50**. The first and second semiconductor chips **C1** and **C2** may be configured to have substantially the same technical features as the first and second semiconductor chips **C1** and **C2** described with reference to FIG. 3, and thus a detailed description thereof may be omitted.

[0073] The connection terminals **30** may be provided between and attached to the first bonding pads **BP1** of the first semiconductor chip **C1** and the second bonding pads **BP2** of the second semiconductor chip **C2**. An under-fill layer **35** may be provided to fill a space between the first and second semiconductor chips **C1** and **C2** and between the connection terminals **30**.

[0074] The under-fill layer **35** may be formed of or include at least one of, for example, thermosetting resins or photo-curable resins. The under-fill layer **35** may include an inorganic filler or an organic filler. As another example, the under-fill layer **35** may be omitted, and the mold layer **50** may be provided to fill a space between the first and second semiconductor chips **C1** and **C2**.

[0075] The mold layer **50** may be provided on the power delivery network PDN of the first semiconductor chip **C1** to cover the second semiconductor chip **C2**. The mold layer **50** may have a side surface that is aligned to a side surface of the first semiconductor chip **C1**. The mold layer **50** may have a top surface that is substantially coplanar with the rear surface (or a bottom surface) of the second semiconductor substrate **20**. The mold layer **50** may be formed of or include at least one of insulating polymers (e.g., an epoxy molding compound). In the case where the under-fill layer **35** is omitted, the space between the first and second semiconductor chips **C1** and **C2** may be filled with the mold layer **50**.

[0076] According to the example embodiment shown in FIG. 5B, the semiconductor package **100** may include the first and second semiconductor chips **C1** and **C2** that are bonded to each other, and the first semiconductor chip **C1** may include the first semiconductor substrate **10**, the logic structure IC, and the power delivery network PDN, as described with reference to FIG. 3.

[0077] The second semiconductor chip **C2** may include the capacitor layer PDC integrated on the second semiconductor substrate **20**. In an example embodiment, the capacitor layer PDC may include the lower and upper interconnection lines INCa and INCb and metal-insulator-metal (MIM) capacitors CAP.

[0078] For example, the MIM capacitors CAP may include the bottom electrode BE, the top electrode TE, and the capacitor dielectric layer DIL therebetween. The bottom electrode BE, the capacitor dielectric layer DIL, and the top electrode TE may be disposed to be parallel to a top surface of the second semiconductor substrate **20**.

[0079] The bottom electrode BE may be connected to the lower interconnection lines through the contact plugs. The bottom electrode BE may be formed by depositing a metal layer on an insulating layer and patterning the metal layer.

[0080] The capacitor dielectric layer DIL and the top electrode TE may be sequentially stacked on the bottom electrode BE. The top electrode TE may be connected to the upper interconnection lines through the contact plugs.

[0081] FIG. 6 is a schematic sectional view illustrating a semiconductor package according to an example embodiment of the inventive concepts. FIG. 7 is a sectional view illustrating a semiconductor package according to an example embodiment of the inventive concepts. For concise description, elements previously described with reference to FIGS. 1 to 5 may be identified by the same reference number without repeating an overlapping description thereof.

[0082] Referring to FIGS. 6 and 7, the semiconductor package **100** may include the first and second semiconductor chips **C1** and **C2**, which are bonded to each other. Here, the first semiconductor chip **C1** may include the logic structure IC, and the second semiconductor chip **C2** may include the capacitor layer PDC and the power delivery network PDN.

[0083] The first semiconductor chip **C1** may include the first semiconductor substrate **10**, the logic

structure IC, which is provided on the first surface of the first semiconductor substrate **10**, the penetration vias TSV, which penetrates the first semiconductor substrate **10** and are connected to the logic structure IC, and the first bonding pads BP1, which are provided on the second surface of the first semiconductor substrate **10**. A polymer layer, which is formed of or includes an insulating material, may be provided between the first bonding pads BP1.

[0084] The surface insulating layer **120** may be disposed on the second surface of the first semiconductor substrate **10**, and the penetration vias TSV may penetrate the surface insulating layer **120** and the first semiconductor substrate **10** and may be connected to the first, second, and third buried power rails BPR1, BPR2, and BPR3 and the buried signal line BSI.

[0085] The second semiconductor chip C2 may include the second semiconductor substrate **20**, the capacitor layer PDC, which is provided on the second semiconductor substrate **20**, the power delivery network PDN, which is provided on the capacitor layer PDC, and the second bonding pads BP2. The second bonding pads BP2 may be provided in the uppermost metal layer of the power delivery network PDN.

[0086] The capacitor layer PDC may include the lower and upper interconnection lines INCa and INCb and the power decoupling capacitors CAP, as described above.

[0087] The power delivery network PDN may include the power lines INC2, which are stacked with inter-metal insulating layers interposed therebetween. The power lines INC2 may be electrically connected to the lower and upper interconnection lines INCa and INCb and the power decoupling capacitors CAP of the capacitor layer PDC through the contact plugs. The power delivery network PDN may be electrically connected to the first, second, and third buried power rails BPR1, BPR2, and BPR3 of the first semiconductor chip C1 through the first and second bonding pads BP1 and BP2.

[0088] The semiconductor package **100** may include the chip pads **111**, which are provided on the bottom surface of the second semiconductor chip C2, and connection terminals **150** may be attached to the chip pads **111**.

[0089] FIG. **8** is a schematic sectional view illustrating a semiconductor package according to an example embodiment of the inventive concepts. FIG. **9** is a sectional view illustrating a semiconductor package according to an example embodiment of the inventive concepts.

[0090] Referring to FIGS. **8** and **9**, the first semiconductor chip C1 may include the first semiconductor substrate **10**, the logic structure IC, and the power delivery network PDN, and the second semiconductor chip C2 may include the second semiconductor substrate **20** and the capacitor layer PDC. The first semiconductor chip C1 may include the first bonding pads BP1, which are provided in the uppermost metal layer of the logic structure IC, and the second semiconductor chip C2 may include the second bonding pads BP2, which are provided in the lowermost metal layer of the capacitor layer PDC. The first and second bonding pads BP1 and BP2 of the first and second semiconductor chips C1 and C2 may be bonded to each other.

[0091] Further, the first semiconductor chip C1 of the semiconductor package **100** may include the chip pads **111**, which are provided in the lowermost metal layer of the power delivery network PDN.

[0092] The power delivery network PDN of the first semiconductor chip C1 may be provided on the second surface (e.g., a bottom surface) of the first semiconductor substrate **10** and may be electrically connected to the first, second, and third buried power rails BPR1, BPR2, and BPR3 through the penetration vias TSV.

[0093] FIG. **10** is a sectional view illustrating a semiconductor package module including a semiconductor package, according to an example embodiment of the inventive concepts.

[0094] Referring to FIG. **10**, a semiconductor package module **1000** may include the first semiconductor package **100**, second semiconductor packages **200**, a redistribution substrate **300**, a package substrate **500**, and a heat-dissipation structure **600**. The first and second semiconductor packages **100** and **200** may be disposed on a top surface of the redistribution substrate **300**.

[0095] The first semiconductor package **100** may have substantially the same structure as the semiconductor package **100** in the previously-described example embodiment. For example, the first semiconductor package **100** may include the first and second semiconductor chips **C1** and **C2**, which are bonded to each other, and the first and second semiconductor chips **C1** and **C2** may include the logic structure **IC** and the capacitor layer **PDC**, respectively.

[0096] The second semiconductor packages **200** may be disposed on the redistribution substrate **300** to be spaced apart from the first semiconductor package **100**. Each of the second semiconductor packages **200** may include a plurality of memory chips **210**, which are vertically stacked. The memory chips **210** may be electrically connected to each other through lower and upper chip pads **221** and **223**, chip through vias **225**, and connection bumps **230**. The memory chips **210** may be stacked on the redistribution substrate **300** in such a way that side surfaces thereof are aligned to each other. An adhesive layer may be provided between each adjacent pair of the memory chips **210**. For example, the adhesive layer may be a polymer tape including an insulating material. The adhesive layer may be interposed between the connection bumps **230** to mitigate or prevent a short circuit issue from occurring between the connection bumps **230**.

[0097] The first and second semiconductor packages **100** and **200** may be connected to the redistribution substrate **300** through first connection terminals **150**. The first connection terminals **150** may be attached to the lower chip pads **111** and **221** of the first and second semiconductor packages **100** and **200**. The first connection terminals **150** may include at least one of solder balls, conductive bumps, or conductive pillars. The first connection terminals **150** may be formed of or include at least one of copper, tin, or lead. For example, the first connection terminals **150** may have a thickness of about 30 μm to about 70 μm .

[0098] A mold layer **400** may be provided on the redistribution substrate **300** to cover the first and second semiconductor packages **100** and **200**. A side surface of the mold layer **400** may be aligned to a side surface of the redistribution substrate **300**. A top surface of the mold layer **400** may be substantially coplanar with top surfaces of the first and second semiconductor packages **100** and **200**. The mold layer **400** may be formed of or include at least one of insulating polymers (e.g., an epoxy molding compound).

[0099] A first under-fill layer may be interposed between the first semiconductor package **100** and the redistribution substrate **300** and between the second semiconductor packages **200** and the redistribution substrate **300**. The first under-fill layer may be provided to fill a space between the first connection terminals **150**. The first under-fill layer may be formed of or include at least one of, for example, thermosetting resins or photo-curable resins. The first under-fill layer may further include an inorganic filler or an organic filler. In an example embodiment, the first under-fill layer may be omitted, and the spaces between the first and second semiconductor packages **100** and **200** and the redistribution substrate **300** may be filled with the mold layer **400**.

[0100] The redistribution substrate **300** may be disposed on the package substrate **500** and may be connected to the package substrate **500** through second connection terminals **350**. The redistribution substrate **300** may include a plurality of insulating layers, which are sequentially stacked, and redistribution patterns, which are provided in each of the insulating layers. The redistribution patterns, which are provided in different insulating layers, may be electrically connected to each other through via portions.

[0101] The second connection terminals **350** may be attached to lower pads of the redistribution substrate **300**. The second connection terminals **350** may be solder balls, which are formed of tin, lead, copper, or the like. The second connection terminals **350** may have a thickness of about 40 μm to about 80 μm .

[0102] The package substrate **500** may be, for example, a printed circuit board, a flexible substrate, a tape substrate, or the like. In an example embodiment, the package substrate **500** may be one of a flexible printed circuit board, a rigid printed circuit board, or combinations thereof, in which internal lines **521** are provided.

[0103] The package substrate **500** may have a top surface and a bottom surface, which are opposite to each other, and may include upper coupling pads **511**, outer coupling pads **513**, and the internal lines **521**. The upper coupling pads **511** may be arranged on the top surface of the package substrate **500**, and the outer coupling pads **513** may be arranged on the bottom surface of the package substrate **500**. The upper coupling pads **511** may be electrically connected to the outer coupling pads **513** through the internal lines **521**. Outer coupling terminals **550** may be attached to the outer coupling pads **513**. A ball grid array (BGA) may be provided as the outer coupling terminals **550**.

[0104] The heat-dissipation structure **600** may be formed of or include at least one of thermally conductive materials. The thermally conductive materials may include metallic materials (e.g., copper and/or aluminum) or carbon-containing materials (e.g., graphene, graphite, and/or carbon nanotube). The heat-dissipation structure **600** may have a relatively high thermal conductivity. As an example, a single metal layer or a plurality of stacked metal layers may be used as the heat-dissipation structure **600**. As another example, the heat-dissipation structure **600** may include a heat sink or a heat pipe. As other example, the heat-dissipation structure **600** may be realized using a water cooling method.

[0105] A heat conduction layer **650** may be interposed between the first and second semiconductor packages **100** and **200** and the heat-dissipation structure **600**. The heat conduction layer **650** may be in contact with the top surfaces of the first and second semiconductor packages **100** and **200** and a bottom surface of the heat-dissipation structure **600**. The heat conduction layer **650** may be formed of or include a thermal interface material (TIM). The thermal interface material may include, for example, polymer and thermally conductive particles. The thermally conductive particles may be dispersed in the polymer. During the operation of the semiconductor package, heat produced in the semiconductor package may be transferred to the heat-dissipation structure **600** through the heat conduction layer **650**.

[0106] FIGS. **11** to **15** are sectional views illustrating a method of fabricating a semiconductor package, according to an example embodiment of the inventive concepts.

[0107] Referring to FIG. **11**, the first semiconductor substrate **10** may be provided. For example, the first semiconductor substrate **10** may be a silicon substrate. The first semiconductor substrate **10** may include chip regions CR and a scribe line region between the chip regions CR. The first semiconductor substrate **10** may include the first surface **10a** and the second surface **10b**, which are opposite to each other.

[0108] In each of the chip regions CR, the first and second active patterns AP1 and AP2 may be formed on the first surface **10a** of the first semiconductor substrate **10**. The first and second active patterns AP1 and AP2 may be line-shaped patterns, which are extended in the first direction D1 and parallel to each other, as previously described with reference to FIG. **2**. The first and second active patterns AP1 and AP2 may be defined by trenches, which are formed by patterning the first semiconductor substrate **10**. For example, the first and second active patterns AP1 and AP2 may be portions of the first semiconductor substrate **10**, which are defined by the trenches formed in the first semiconductor substrate **10**.

[0109] The device isolation layer **11** may be formed between the first and second active patterns AP1 and AP2. The device isolation layer **11** may be formed to have a top surface, which is lower than top surfaces of the first and second active patterns AP1 and AP2, and thereby to expose upper portions of the first and second active patterns AP1 and AP2.

[0110] The first, second, and third buried power rails BPR1, BPR2, and BPR3 and the buried signal line BSI may be formed before or after the formation of the first and second active patterns AP1 and AP2. The first, second, and third buried power rails BPR1, BPR2, and BPR3 and the buried signal line BSI may be formed of or include at least one of metallic materials (e.g., tungsten, aluminum, titanium tantalum, titanium nitride, tantalum nitride, and/or tungsten nitride).

[0111] The first, second, and third buried power rails BPR1, BPR2, and BPR3 and the buried signal line BSI may be formed by patterning the device isolation layer **11** and the first semiconductor

substrate **10** to form trenches, filling the trenches with a metal layer, and recessing (or planarizing) the metal layer.

[0112] The first, second, and third buried power rails **BPR1**, **BPR2**, and **BPR3** and the buried signal line **BSI** may have top surfaces that are located at a level lower than the top surfaces of the first and second active patterns **AP1** and **AP2**. The first, second, and third buried power rails **BPR1**, **BPR2**, and **BPR3** and the buried signal line **BSI** may have bottom surfaces that are located at a level lower than a bottom surface of the device isolation layer **11**.

[0113] The gate structures **GS** (e.g., see FIG. **2**) and the active contacts **AC1** and **AC2** may be formed after the formation of the first, second, and third buried power rails **BPR1**, **BPR2**, and **BPR3** and the buried signal line **BSI**. The active contacts **AC1** and **AC2** may be formed to penetrate the first interlayer insulating layer **13** and to be in contact with the first or second active patterns **AP1** or **AP2**. Each of the active contacts **AC1** and **AC2** may include a barrier metal layer and a metal layer. The active contacts **AC1** and **AC2** may be formed to have top surfaces that are substantially coplanar with a top surface of the first interlayer insulating layer **13**.

[0114] The second interlayer insulating layer **15** may be formed on the first interlayer insulating layer **13** to cover the top surfaces of the active contacts **AC1** and **AC2**.

[0115] Referring to FIG. **12**, the signal lines **INC1** may be stacked on the second interlayer insulating layer **15** with an inter-metal insulating layer interposed therebetween. The signal lines **INC1**, which are vertically stacked, may be electrically connected to each other through contact plugs.

[0116] Referring to FIG. **13**, a thinning process may be performed to reduce a thickness of the first semiconductor substrate **10**. The thinning process may include grinding or polishing the second surface **10b** of the first semiconductor substrate **10** and anisotropically and/or isotropically etching the first semiconductor substrate **10**.

[0117] For the thinning process on the first semiconductor substrate **10**, a dummy substrate **DMY** may be attached to the uppermost insulating layer of the logic structure **IC** using an adhesive layer **110**. After the attachment of the dummy substrate **DMY**, the first semiconductor substrate **10** may be vertically inverted. A portion of the first semiconductor substrate **10** may be removed by the grinding or polishing process, and then, the anisotropic or isotropic etching process may be performed to remove surface defects from the remaining portion of the first semiconductor substrate **10**.

[0118] The surface insulating layer **120** may be formed on the second surface **10b** of the first semiconductor substrate **10**, and then, the second surface **10b** of the first semiconductor substrate **10** may be patterned to form penetration holes exposing the first, second, and third buried power rails **BPR1**, **BPR2**, and **BPR3** and the buried signal line **BSI**. The penetration holes may be formed to have a vertical length of about 1 μm or less. Next, a metallic material may be formed to fill the penetration holes, and the penetration vias **TSV** may be formed by planarizing the metallic material to expose the surface insulating layer **120**.

[0119] Referring to FIG. **14**, the power delivery network **PDN** may be formed on the surface insulating layer **120**. The formation of the power delivery network **PDN** may include forming the power lines **INC2** with inter-metal insulating layers interposed therebetween. Further, the first bonding pads **BP1** may be formed in the uppermost metal layer of the power delivery network **PDN**. The first bonding pads **BP1** may be electrically connected to the power lines **INC2**.

[0120] Referring to FIG. **15**, the second semiconductor substrate **20** including the capacitor layer **PDC** may be provided on the power delivery network **PDN**.

[0121] For example, the second semiconductor substrate **20** may be a silicon substrate. The second semiconductor substrate **20** may include the chip regions **CR** and the scribe line region between the chip regions **CR**, similar to the first semiconductor substrate **10**.

[0122] The power decoupling capacitors **CAP** may be formed on the chip regions **CR** of the second semiconductor substrate **20**. The lowermost metal layer of the capacitor layer **PDC** may include the

second bonding pads BP2.

[0123] The second semiconductor substrate **20** may be aligned to the first semiconductor substrate **10** such that the chip regions CR of the first semiconductor substrate **10** are vertically overlapped with the chip regions CR of the second semiconductor substrate **20**.

[0124] The first bonding pads BP1 and the second bonding pads BP2 may be disposed to correspond to each other and may be directly bonded to each other. The first and second bonding pads BP1 and BP2 may be formed of or include at least one of tungsten (W), aluminum (Al), copper (Cu), tungsten nitride (WN), tantalum nitride (TaN), or titanium nitride (TiN), and in the case where the first and second bonding pads BP1 and BP2 are formed of copper (Cu), the first and second bonding pads BP1 and BP2 may be physically and electrically connected to each other in a copper (Cu)-copper (Cu) bonding manner. Further, surfaces of the insulating layers of the capacitor layer PDC and the power delivery network PDN may be bonded to each other in a dielectric-dielectric bonding manner.

[0125] For the bonding between the first and second bonding pads BP1 and BP2, pressure and heat may be applied to the second semiconductor substrate **20**. For example, the first and second bonding pads BP1 and BP2 may be treated by an annealing process, which is performed at a temperature of about 100° C. to 500° C. under pressure lower than about 30 MPa. However, the inventive concepts are not limited to this example, and the pressure and temperature conditions for the bonding process may be variously changed.

[0126] After the bonding between the first and second bonding pads BP1 and BP2, a cutting process may be performed along the scribe line region to separate the chip regions CR of the first and second semiconductor substrates **10** and **20** from each other, and thus the semiconductor package **100** may be formed to have the same structure as described with reference to FIG. 3. Here, the cutting process may be performed using a sawing blade or a laser beam.

[0127] FIG. 16 is a sectional view illustrating a method of fabricating a semiconductor package, according to an example embodiment of the inventive concepts.

[0128] Referring to FIG. 16, the first semiconductor substrate **10**, on which the logic structure IC and the power delivery network PDN are formed, may be provided, as described with reference to FIGS. 12 to 14.

[0129] A plurality of second semiconductor chips C2 may be provided on the chip regions CR of the first semiconductor substrate **10**, respectively. Each of the second semiconductor chips C2 may include the second semiconductor substrate **20** and the capacitor layer PDC on the second semiconductor substrate **20**, as described above, and the second bonding pads BP2 may be disposed in the lowermost metal layer of the capacitor layer PDC.

[0130] The second semiconductor chips C2 may be provided in such a way that the second bonding pads BP2 thereof face the first bonding pads BP1 on the first semiconductor substrate **10**. The first and second bonding pads BP1 and BP2 may be connected to each other through the connection terminals **30**.

[0131] Next, the under-fill layer **35** may be formed to fill a space between the power delivery network PDN and the capacitor layer PDC, and the mold layer **50** (e.g., see FIG. 5A) may be formed on the insulating layer of the power delivery network PDN.

[0132] The mold layer **50** (e.g., see FIG. 5A) may be formed to thickly cover the second semiconductor chips C2, and then a grinding process may be performed to expose the second semiconductor substrate **20**.

[0133] After the formation of the mold layer **50**, a cutting process may be performed along the scribe line region to form the semiconductor package **100** described with reference to FIG. 5A or 5B.

[0134] FIGS. 17 and 18 are sectional views illustrating a method of fabricating a semiconductor package, according to an example embodiment of the inventive concepts.

[0135] Referring to FIG. 17, the logic structure IC may be formed on the first surface **10a** of the

first semiconductor substrate **10**, as previously described with reference to FIGS. **11** to **13**, and then, the penetration vias TSV may be formed to penetrate the first semiconductor substrate **10** and to be connected to the first, second, and third buried power rails BPR1, BPR2, and BPR3.

[0136] After the formation of the penetration vias TSV, the first bonding pads BP1 may be formed on the second surface **10b** of the first semiconductor substrate **10**. Some of the first bonding pads BP1 may be connected to the penetration vias TSV.

[0137] Referring to FIG. **18**, the second semiconductor substrate **20**, on which the capacitor layer PDC and the power delivery network PDN are formed, may be provided on the first semiconductor substrate **10**.

[0138] The capacitor layer PDC, which includes the power decoupling capacitors CAP, may be formed on a front surface of the second semiconductor substrate **20** (e.g., a first surface of the second semiconductor substrate **20** facing the power delivery network PDN), and the power delivery network PDN, which includes the power lines INC2 electrically connected to the power decoupling capacitors CAP, may be formed on the capacitor layer PDC. The lowermost metal layer of the power delivery network PDN may be formed to include the second bonding pads BP2.

[0139] Next, the first semiconductor substrate **10** and the second semiconductor substrate **20** may be bonded to each other such that the first bonding pads BP1 of the first semiconductor substrate **10** are in direct contact with the second bonding pads BP2 of the second semiconductor substrate **20**. Accordingly, the power lines INC2 may be electrically connected to the buried power rails BPR1, BPR2, and BPR3 through the first and second bonding pads BP1 and BP2 and the penetration vias TSV.

[0140] After the bonding between the first and second bonding pads BP1 and BP2, a cutting process may be performed along the scribe line region to separate the chip regions CR of the first and second semiconductor substrates **10** and **20** from each other, and thus the semiconductor package **100** may be formed to have the same structure as described with reference to FIGS. **6** and **7**.

[0141] FIGS. **19** to **22** are sectional views illustrating a method of fabricating a semiconductor package, according to an example embodiment of the inventive concepts.

[0142] Referring to FIG. **19**, the logic structure IC may be formed on the first surface **10a** of the first semiconductor substrate **10**, as described with reference to FIGS. **10** and **11**.

[0143] The signal lines INC1 may be formed on the first surface **10a** of the first semiconductor substrate **10**, and the first bonding pads BP1 may be formed in the uppermost metal layer of the signal lines INC1.

[0144] Referring to FIG. **20**, the second semiconductor substrate **20** including the capacitor layer PDC may be provided on the first semiconductor substrate **10**.

[0145] The capacitor layer PDC may include the power decoupling capacitors CAP, and the lowermost metal layer of the capacitor layer PDC may include the second bonding pads BP2 connected to the power decoupling capacitors CAP.

[0146] The first semiconductor substrate **10** and the second semiconductor substrate **20** may be bonded to each other such that the first bonding pads BP1 in the logic structure IC are directly bonded to the second bonding pads BP2 in the capacitor layer PDC.

[0147] Next, referring to FIG. **21**, the first semiconductor substrate **10** may be vertically inverted, and then a thinning process may be performed on the first semiconductor substrate **10**, as described with reference to FIG. **13**.

[0148] After the thinning process, the surface insulating layer **120** may be formed on the second surface **10b** of the first semiconductor substrate **10**. Next, the second surface **10b** of the first semiconductor substrate **10** may be patterned to form the penetration vias TSV, which are electrically connected to the first, second, and third buried power rails BPR1, BPR2, and BPR3 and the buried signal line BSI.

[0149] Referring to FIG. **22**, the power delivery network PDN, which is electrically connected to

the penetration vias TSV, may be formed on the surface insulating layer **120**. The formation of the power delivery network PDN may include forming insulating layers and the power lines INC2, which are interposed between the insulating layers, on the surface insulating layer **120**.

[0150] The chip pads **111** may be formed in the uppermost metal layer of the power delivery network PDN and on each chip region CR. After the formation of the chip pads **111**, a cutting process may be performed along the scribe line region. Accordingly, the semiconductor package **100** may be formed to have the same structure as described with reference to FIGS. **8** and **9**.

[0151] According to an example embodiment of the inventive concepts, a power decoupling capacitor may be provided adjacent to a power delivery network. Accordingly, when a semiconductor package executes a high frequency operation, a power noise may be reduced. Thus, operation characteristics of the semiconductor package may be improved.

[0152] According to an example embodiment of the inventive concepts, a second semiconductor chip including the power decoupling capacitor may be bonded to a first surface of a first semiconductor substrate, on which a logic structure is integrated, and then the power delivery network may be formed on a second surface of the first semiconductor substrate. That is, a dummy substrate is not needed to form the power delivery network on the second surface of the first semiconductor substrate.

[0153] While some example embodiments of the inventive concepts have been particularly shown and described, it will be understood by one of ordinary skill in the art that variations in form and detail may be made therein without departing from the spirit and scope of the attached claims.

Claims

1. A method of fabricating a semiconductor package, the method comprising: providing a first semiconductor substrate having a first surface and a second surface opposite to the first surface; forming a logic structure on the first surface of the first semiconductor substrate; forming penetration vias penetrating the first semiconductor substrate to be connected to the logic structure; forming a power delivery network on the second surface of the first semiconductor substrate, the power delivery network connected to the penetration vias; forming first bonding pads connected to the power delivery network; forming a capacitor layer including power decoupling capacitors on a top surface of a second semiconductor substrate; forming second bonding pads connected to the capacitor layer; and bonding the first bonding pads to the second bonding pads, respectively.
2. The method of claim 1, wherein forming the logic structure comprises: forming active patterns on the first surface of the first semiconductor substrate; forming buried power rails in the first semiconductor substrate; and forming active contacts connecting the buried power rails to the active patterns.
3. The method of claim 2, wherein forming the logic structure further comprises: forming signal lines on an interlayer insulating layer covering the active contacts.
4. The method of claim 2, wherein the penetration vias connects the buried power rails in the logic structure to the power delivery network.
5. The method of claim 1, further comprising: attaching a dummy substrate on the logic structure; and grinding the second surface of the first semiconductor substrate.
6. The method of claim 1, further comprising: performing a cutting process to the first and second semiconductor substrates to form a plurality of chips which are separated from each other, after bonding the first bonding pads to the second bonding pads.
7. The method of claim 1, wherein the forming the capacitor layer comprises: forming a bottom electrode pad on the second semiconductor substrate; forming a plurality of bottom electrodes on the bottom electrode pad; forming a capacitor dielectric layer covering the bottom electrodes with a uniform thickness; and forming a top electrode on the capacitor dielectric layer, the top electrode covering the plurality of the bottom electrodes.

- 8.** The method of claim 7, wherein each of the bottom electrodes includes a bottom portion and a sidewall portion, which is vertically extended from the bottom portion to define an empty space.
- 9.** A method of fabricating a semiconductor package, the method comprising: providing a first semiconductor substrate having a first surface and a second surface opposite to the first surface; forming active patterns on the first surface of the first semiconductor substrate; forming buried power rails in the first semiconductor substrate; forming active contacts connecting the buried power rails to the active patterns; forming signal lines on a first interlayer insulating layer covering the active contacts; attaching a dummy substrate on a second interlayer insulating layer covering the signal lines; performing a thinning process on the second surface of the first semiconductor substrate; forming penetration vias penetrating the first semiconductor substrate to be connected to the buried power rails; forming a power delivery network on the second surface of the first semiconductor substrate, the power delivery network connected to the penetration vias; forming first bonding pads connected to the power delivery network; providing a second semiconductor substrate; forming a capacitor layer including a plurality of power decoupling capacitors on a top surface of the second semiconductor substrate; forming second bonding pads connected to the capacitor layer; bonding the first bonding pads to the second bonding pads, respectively; and performing a cutting process to the first and second semiconductor substrates to form a plurality of chips which are separated from each other, after bonding the first bonding pads to the second bonding pads.
- 10.** The method of claim 9, wherein the plurality of power decoupling capacitors comprises: a plurality of bottom electrodes on the second semiconductor substrate; a capacitor dielectric layer covering surfaces of the plurality of bottom electrodes; and a top electrode on the capacitor dielectric layer.
- 11.** The method of claim 10, wherein each of the bottom electrodes includes a bottom portion and a sidewall portion, which is vertically extended from the bottom portion to define an empty space.
- 12.** The method of claim 10, wherein each of the bottom electrodes has a pillar shape perpendicular to the top surface of the second semiconductor substrate.
- 13.** The method of claim 9, wherein the plurality of power decoupling capacitors comprises: a bottom electrode on the second semiconductor substrate; a top electrode; and a capacitor dielectric layer between the bottom electrode and the top electrode, and the bottom electrode, the capacitor dielectric layer, and the top electrode are parallel to the top surface of the second semiconductor substrate.
- 14.** The method of claim 9, wherein the power delivery network comprises power lines on the second surface of the first semiconductor substrate, and the first bonding pads are connected to the power lines.
- 15.** The method of claim 9, wherein the penetration vias have a diameter ranging from 50 nm to 150 nm and a vertical length ranging from 300 nm to 1 μ m.
- 16.** A method of fabricating a semiconductor package, the method comprising: forming a logic structure on a first surface of a first semiconductor substrate; forming a power delivery network on a second surface of the first semiconductor substrate, the second surface being opposite to the first surface; forming penetration vias penetrating the first semiconductor substrate and connecting the logic structure to the power delivery network; forming a capacitor layer including power decoupling capacitors on a second semiconductor substrate; and bonding the second semiconductor substrate to the first semiconductor substrate so that the power delivery network and the capacitor layer are vertically adjacent to each other.
- 17.** The method of claim 16, further comprising: forming first bonding pads connected to the power delivery network; and forming second bonding pads connected to the power decoupling capacitors, wherein bonding the second semiconductor substrate to the first semiconductor substrate comprises directly bonding the first bonding pads to the second bonding pads, respectively.
- 18.** The method of claim 16, wherein forming the logic structure comprises: forming active patterns

on the first surface of the first semiconductor substrate; forming buried power rails in the first semiconductor substrate; and forming active contacts connecting the buried power rails to the active patterns.

19. The method of claim 16, before forming the power delivery network, further comprising: attaching a dummy substrate on a second interlayer insulating layer covering signal lines; and performing a thinning process on the second surface of the first semiconductor substrate.

20. The method of claim 16, wherein forming the capacitor layer comprises: forming a bottom electrode pad on the second semiconductor substrate; forming a plurality of bottom electrodes on the bottom electrode pad; forming a capacitor dielectric layer covering the bottom electrodes with a uniform thickness; and forming a top electrode on the capacitor dielectric layer, the top electrode covering the plurality of the bottom electrodes.
