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Semiconductor device and methods of manufacturing the same

Abstract

Provided is a semiconductor device including a substrate including a cell array area and a peripheral circuit area and including a plurality of first active areas defined in the cell array area and at least one second active area defined in the peripheral circuit area; a plurality of bit lines arranged in the cell array area of the substrate and extending in a first direction; a plurality of cell pad structures arranged between the bit lines and each including a first conductive layer, a first intermediate layer, and a first metal layer that are sequentially arranged on a top surface of the first active area; and a peripheral circuit gate electrode disposed on the peripheral circuit area of the substrate and including a second conductive layer, a second intermediate layer, and a second metal layer sequentially arranged on the at least one second active area.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

(1) This application is based on and claims priority under 35 U.S.C. § 119 to Korean Patent

BACKGROUND

(2) Inventive concepts relate to a semiconductor device and/or a method of manufacturing the same, and more particularly, to a semiconductor device including a cell capacitor and/or a method of manufacturing the same.

(3) As semiconductor devices are being downscaled, sizes of individual micro circuit patterns for implementing semiconductor devices are being further reduced. Also, as the size of individual microcircuit patterns is reduced, the difficulty of a manufacturing process may increase due to a difference in pattern density between the interior of a cell array area and a peripheral area.

SUMMARY

(4) Inventive concepts provide a semiconductor device capable of preventing or reducing the likelihood of and/or impact from process defects due to a step difference occurring at edge portions of a cell array area.

(5) Alternatively or additionally, inventive concepts provide a method of manufacturing a semiconductor device capable of preventing or reducing the likelihood of and/or impact from process defects due to a step difference occurring at edge portions of a cell array area.

(6) According to some example embodiments, there is provided a semiconductor device including a substrate including a cell array area and a peripheral circuit area. The semiconductor device includes a plurality of first active areas defined in the cell array area and at least one second active area defined in the peripheral circuit area; a plurality of bit lines in the cell array area of the substrate and extending in a first direction; a plurality of cell pad structures between the bit lines and each including a first conductive layer, a first intermediate layer, and a first metal layer that are sequentially arranged on a top surface of the first active area; and a peripheral circuit gate electrode on the peripheral circuit area of the substrate and including a second conductive layer, a second intermediate layer, and a second metal layer sequentially arranged on the at least one second active area.

(7) According to some example embodiments, there is provided a semiconductor device including a substrate including a cell array area, a boundary area, and a peripheral circuit area and including a plurality of first active areas defined in the cell array area and at least one second active area defined in the peripheral circuit area; a plurality of bit lines in the cell array area of the substrate and extending in a first direction; a plurality of cell pad structures between two adjacent bit lines from among the plurality of bit lines and each including a first conductive layer and a first metal layer that are sequentially arranged on a top surface of the first active area; and a peripheral circuit gate electrode on the peripheral circuit area of the substrate and including a second conductive layer and a second metal layer sequentially arranged on the at least one second active area. A height of the cell pad structures is substantially the same as a height of the peripheral circuit gate electrode.

(8) According to some example embodiments, there is provided a semiconductor device including a substrate including a cell array area, a boundary area, and a peripheral circuit area and including a plurality of first active areas defined in the cell array area and at least one second active area defined in the peripheral circuit area; a plurality of bit lines arranged in the cell array area of the substrate and extending in a first direction; a bit line contact between the bit lines and the first active areas and electrically connecting the bit lines to the first active areas; a bit line contact spacer surrounding sidewalls of the bit line contact; a plurality of cell pad structures between two adjacent bit lines from among the plurality of bit lines and each including a first conductive layer, a first intermediate layer, and a first metal layer that are sequentially arranged on a top surface of the first active area; a plurality of landing pads respectively arranged on the cell pad structures; and a peripheral circuit gate electrode on the peripheral circuit area of the substrate and including a second conductive layer, a second intermediate layer, and a second metal layer sequentially

arranged on the at least one second active area. The second metal layer includes the same material as the material included in the first metal layer.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

- (1) Embodiments of inventive concepts will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings in which:
- (2) FIG. 1 is a layout diagram showing a semiconductor device according to some example embodiments;
- (3) FIG. 2 is an enlarged layout view of a portion A of FIG. 1;
- (4) FIG. 3 is a cross-sectional view taken along a line B1-B1' of FIG. 2;
- (5) FIG. 4 is a cross-sectional view taken along a line B2-B2' of FIG. 2;
- (6) FIG. 5 is an enlarged cross-sectional view of a portion CX1 of FIG. 3;
- (7) FIG. 6 is an enlarged cross-sectional view of a portion CX2 of FIG. 3;
- (8) FIG. 7 is a cross-sectional view of a semiconductor device according to some example embodiments of inventive concepts;
- (9) FIG. 8 is an enlarged cross-sectional view of a portion CX1 of FIG. 7;
- (10) FIG. 9 is an enlarged cross-sectional view of a portion CX2 of FIG. 7;
- (11) FIGS. 10A to 21 are cross-sectional views showing a method of manufacturing a semiconductor device according to some example embodiments, wherein, in detail, FIGS. 10A, 12 to 18, 19A, 20, and 21 are cross-sectional views corresponding to cross-sections taken along a line B1-B1' of FIG. 2, and FIGS. 10B, 11, and 19B are cross-sectional views corresponding to cross-sections taken along a line B2-B2' of FIG. 2.

DETAILED DESCRIPTION OF VARIOUS EXAMPLE EMBODIMENTS

- (12) FIG. 1 is a layout diagram showing a semiconductor device 100 according to some example embodiments. FIG. 2 is an enlarged layout view of a portion A of FIG. 1. FIG. 3 is a cross-sectional view taken along a line B1-B1' of FIG. 2. FIG. 4 is a cross-sectional view taken along a line B2-B2' of FIG. 2. FIG. 5 is an enlarged cross-sectional view of a portion CX1 of FIG. 3. FIG. 6 is an enlarged cross-sectional view of a portion CX2 of FIG. 3.
- (13) Referring to FIGS. 1 to 6, the semiconductor device 100 may include a substrate 110 including a cell array area MCA and a peripheral circuit area PCA. The cell array area MCA may be or may include a memory cell area of a DRAM device, and the peripheral circuit area PCA may be or may include a core area or a peripheral circuit area of the DRAM device; however, example embodiments are not limited thereto. For example, the cell array area MCA may include a cell transistor CTR and a capacitor structure 180 connected thereto, and the peripheral circuit area PCA may include a peripheral circuit transistor PTR for transferring signals and/or power to the cell transistor CTR included in the cell array area MCA. In some example embodiments, the peripheral circuit transistor PTR may configure various circuits such as a command decoder, control logic, an address buffer, a row decoder, a column decoder, a sense amplifier, a redundancy circuit, and/or a data input/output circuit.
- (14) A device isolation trench 112T may be formed in the substrate 110, and a device isolation layer 112 may be formed in the device isolation trench 112T. The device isolation layer 112 may define a plurality of first active areas AC1 on the substrate 110 in the cell array area MCA and may define a plurality of second active areas AC2 on the substrate 110 in the peripheral circuit area PCA.
- (15) A boundary trench 114T may be formed in a boundary area BA between the cell array area MCA and the peripheral circuit area PCA, and a boundary structure 114 may be formed in the boundary trench 114T. When viewed from above (e.g. in plan view), the boundary trench 114T may be provided to surround all sides. e.g. four sides of the cell array area MCA. The boundary

structure **114** may include a buried insulation layer **114A**, an insulation liner **114B**, and a gap-fill insulation layer **114C** arranged inside the boundary trench **114T**.

(16) The buried insulation layer **114A** may be conformally disposed on the inner wall of the boundary trench **114T**. In some example embodiments, the buried insulation layer **114A** may include silicon oxide. For example, the buried insulation layer **114A** may include silicon oxide formed through one or more of an atomic layer deposition (ALD) process, a chemical vapor deposition (CVD) process, a plasma enhanced CVD (PECVD) process, a low pressure CVD (LPCVD) process, etc.

(17) The insulation liner **114B** may be conformally disposed on the inner wall of the boundary trench **114T** on the buried insulation layer **114A**. In some example embodiments, the insulation liner **114B** may include silicon nitride. For example, the insulation liner **114B** may include silicon nitride formed through one or more of an ALD process, a CVD process, a PECVD process, an LPCVD process, etc.

(18) The gap-fill insulation layer **114C** may fill the boundary trench **114T** on the insulation liner **114B**. In some example embodiments, the gap-fill insulation layer **114C** may include one or more of a silicon oxide like Tonen Silazene (TOSZ), undoped silicate glass (USG), boro-phospho-silicate glass (BPSG), phosphosilicate glass (PSG), flowable oxide (FOX), plasma enhanced deposition of tetra-ethyl-ortho-silicate (PE-TEOS), or fluoride silicate glass (FSG).

(19) In the cell array area MCA, the first active areas AC1 may be arranged to have long axes in a diagonal direction with respect to a first horizontal direction X and a second horizontal direction Y. The diagonal direction may be a direction of between 10 degrees and 80 degrees with respect to the first horizontal direction X and the second horizontal direction Y, for example may be a direction 70 degrees with respect to the first horizontal direction X; however, example embodiments are not limited thereto. A plurality of word lines WL may extend parallel to one another along the first horizontal direction X across the first active areas AC1. A plurality of bit lines BL may extend parallel to one another along the second horizontal direction Y on the word lines WL. The bit lines BL may be connected to the first active areas AC1 via direct contacts DC.

(20) A plurality of cell pad structures **130** may be formed between two bit lines BL adjacent to each other from among the bit lines BL. The cell pad structures **130** may be arranged in a row in the first horizontal direction X and the second horizontal direction Y. A plurality of landing pads LP may be formed on the cell pad structures **130**. The cell pad structures **130** and the landing pads LP may connect lower electrodes **182** of the capacitor structure **180** formed over the bit lines BL to the first active areas AC1. The landing pads LP may be arranged to partially overlap the cell pad structures **130**, respectively.

(21) The substrate **110** may include silicon. e.g., monocrystalline silicon, polycrystalline silicon, or amorphous silicon. In some example embodiments, the substrate **110** may include at least one selected from among Ge, SiGe, SiC, GaAs, InAs, and InP. In some example embodiments, the substrate **110** may include a conductive region, e.g., a well doped with an impurity or a structure doped with an impurity. The device isolation layer **112** may include an oxide film, a nitride film, or a combination thereof.

(22) In the cell array area MCA, a plurality of word line trenches **120T** extending in a first direction (X direction) may be arranged on the substrate **110**, and a buried gate structure **120** may be disposed in the word line trenches **120T**. The buried gate structure **120** may include gate dielectric layers **122**, gate electrodes **124**, and capping insulation layers **126** respectively arranged in the word line trenches **120T**. A plurality of gate electrodes **124** may correspond to the word lines WL shown in FIG. 1.

(23) A plurality of gate dielectric layers **122** may include one or more of a silicon oxide film, a silicon nitride film, a silicon oxynitride film, an oxide/nitride/oxide (ONO) film, or a high-k dielectric film having a dielectric constant higher than that of the silicon oxide film. The gate electrodes **124** may include Ti, TiN, Ta, TaN, W, WN, TiSiN, WSiN, or a combination thereof. A

plurality of capping insulation layers **126** may include a silicon oxide film, a silicon nitride film, a silicon oxynitride film, or a combination thereof.

(24) The word line trenches **120T** may extend from the cell array area MCA into the boundary area BA, and respective end portions of the word line trenches **120T** may vertically overlap the boundary structure **114** in the boundary area BA.

(25) A buffer layer **118** may be formed on the substrate **110**, the buried gate structure **120**, and the boundary structure **114** in the boundary area BA. The buffer layer **118** may include an oxide film, a nitride film, or a combination thereof.

(26) A plurality of bit line contacts or direct contacts DC may be formed in a plurality of bit line contact holes or direct contact holes DCH on the substrate **110**. The direct contacts DC may be connected to the first active area AC1. The direct contacts DC may include TiN, TiSiN, W, tungsten silicide, doped polysilicon, or a combination thereof.

(27) A bit line contact spacer or direct contact spacer DCS may be disposed on the inner wall of the direct contact hole DCH. The direct contact spacer DCS may be disposed on the lower sidewall of the direct contact hole DCH and may cover the lower portion of the direct contact DC.

(28) The bit lines BL may extend long in the second horizontal direction Y over the substrate **110** and the plurality of direct contacts DC. The bit lines BL may be connected to the first active areas AC1 via the direct contacts DC, respectively. The bit lines BL may include ruthenium (Ru), tungsten (W), cobalt (Co), titanium (Ti), titanium nitride (TiN), or a combination thereof.

(29) The bit lines BL may be covered by a plurality of insulation capping structures **140**, respectively. The insulation capping structures **140** may extend in the second horizontal direction Y on the bit lines BL. The insulation capping structures **140** may each include a lower capping pattern **142A** and an upper capping pattern **144A**.

(30) Bit line spacers **150A** may be arranged on both sidewalls of each of the bit lines BL. The bit line spacers **150A** may extend in the second horizontal direction Y on both sidewalls of the bit lines BL, and portions of the bit line spacers **150A** may extend into the direct contact holes DCN and cover the upper portion of the sidewall of the direct contacts DC. Although FIG. 3 shows that the bit line spacer **150A** is a single material layer, in some example embodiments, the bit line spacer **150A** may be formed as a stacked structure of a plurality of spacer layers (not shown), and at least one of the spacer layers may be an air spacer.

(31) The cell pad structures **130** may be arranged between the bit lines BL. For example, one cell pad structure **130** may be disposed between two adjacent bit lines BL at a vertical level lower than that of the bit lines BL. For example, insulation patterns **152** may be disposed between the two cell pad structures **130** arranged in the first horizontal direction X and between two cell pad structures **130** arranged in the second horizontal direction Y, and the insulation pattern **152** may electrically separate two adjacent cell pad structures **130** from each other. Also, a lower portion of the sidewall of the cell pad structure **130** may contact the direct contact spacer DCS, and an upper portion of the sidewall of the cell pad structure **130** may contact the bit line spacer **150A**.

(32) In some example embodiments, the cell pad structures **130** may include a first conductive layer **132A**, a first intermediate layer **134A**, and a first metal layer **136A** sequentially arranged on the first active area AC1. In some example embodiments, the first conductive layer **132A** may include Si, Ge, W, WN, CO, Ni, Al, Mo, Ru, Ti, TiN, Ta, TaN, Cu, or a combination thereof. The first intermediate layer **134A** and the first metal layer **136A** may each include TiN, TiSiN, W, tungsten silicide, or a combination thereof.

(33) As shown in FIG. 5, the bottom surface of the first conductive layer **132A** may be disposed at a level lower than that of a top surface AC1_T of the first active area AC1, and the first conductive layer **132A** may be disposed to cover the top surface AC1_T and a sidewall AC1_S of the first active area AC1. Therefore, a relatively large contact area may be secured between the first conductive layer **132A** and the first active area AC1. In some example embodiments, unlike as shown in FIG. 5, the bottom surface of the first conductive layer **132A** may be disposed at

substantially the same level as the top surface AC1_T of the first active area AC1, and thus the bottom surface of the first conductive layer 132A may have a flat profile.

(34) An insulation layer 154 may be disposed on the cell pad structure 130 to cover the cell pad structure 130 and the insulation pattern 152.

(35) A plurality of insulation fences 156 may be arranged in the second horizontal direction Y between two adjacent bit lines BL. The insulation fences 156 may be arranged on the insulation layer 154 at positions to vertically overlap the word line trenches 120T.

(36) The landing pads LP may be arranged on the cell pad structures 130. The landing pads LP may each include a conductive barrier film 162A and a landing pad conductive layer 164A. The conductive barrier film 162A may include Ti, TiN, or a combination thereof. The landing pad conductive layer 164A may include a metal, a metal nitride, a conductive polysilicon, or a combination thereof. For example, the landing pad conductive layer 164A may include W. The landing pads LP may have a pattern shape of a plurality of islands when viewed from above.

(37) The landing pads LP may be electrically insulated from one another by an insulation pattern 166 surrounding the landing pads LP. The insulation pattern 166 may include at least one of silicon nitride, silicon oxide, and silicon oxynitride.

(38) A first etch stop layer 172 may be disposed on the landing pads LP and the insulation pattern 166 in the cell array area MCA. The capacitor structure 180 may be disposed on the first etch stop layer 172. The capacitor structure 180 may include a plurality of lower electrodes 182, a capacitor dielectric layer 184, and an upper electrode 186.

(39) The lower electrodes 182 may penetrate through the first etch stop layer 172 and extend in a vertical direction Z on the landing pads LP. The bottom portions of the lower electrodes 182 may penetrate through the first etch stop layer 172 and connected to the landing pads LP. The capacitor dielectric layer 184 may be disposed on the lower electrodes 182. The upper electrode 186 may be disposed on the capacitor dielectric layer 184 to cover the lower electrodes 182.

(40) In some example embodiments, the capacitor dielectric layer 184 may include at least one of zirconium oxide, hafnium oxide, titanium oxide, niobium oxide, tantalum oxide, yttrium oxide, strontium titanium oxide, barium strontium titanium oxide, scandium oxide, and lanthanide oxide. The lower electrodes 182 and the upper electrode 186 may include at least one selected from among metals such as ruthenium (Ru), titanium (Ti), tantalum (Ta), niobium (Nb), iridium (Ir), molybdenum (Mo), and tungsten (W), conductive metal nitrides such as titanium nitride (TiN), tantalum nitride (Ta₂N₃), niobium nitride (NbN), molybdenum nitride (MoN), and tungsten nitride (WN), and conductive metal oxides such as iridium oxide (IrO₂), ruthenium oxide (RuO₂), and strontium ruthenium oxide (SrRuO₃).

(41) In some example embodiments, the lower electrodes 182 may each have a pillar shape extending in the vertical direction Z, and the lower electrodes 182 may each have a circular horizontal cross-section. However, the horizontal cross-sectional shape of the lower electrodes 182 is not limited thereto, and the lower electrodes 182 may have a horizontal cross-section of various polygonal shapes and rounded polygonal shapes such as an ellipse, a square, a rounded square, a rhombus, a trapezoid, etc. Alternatively or additionally, although FIG. 3 shows that the lower electrodes 182 have a pillar shape having circular horizontal cross-sections throughout the entire heights thereof, in some example embodiments, the lower electrodes 182 may have a cylindrical shape with a closed bottom.

(42) The peripheral circuit transistor PTR may be disposed on the second active area AC2 in the peripheral circuit area PCA. The peripheral circuit transistor PTR may include a gate dielectric layer 116, a peripheral circuit gate electrode PGS, and a gate capping pattern 142B that are sequentially stacked on the second active area AC2.

(43) The gate dielectric layer 116 may include at least one selected from among a silicon oxide film, a silicon nitride film, a silicon oxynitride film, an oxide/nitride/oxide (ONO) film, or a high-k dielectric film having a dielectric constant higher than that of the silicon oxide film. The gate

capping pattern **142B** may include a silicon nitride film.

(44) The peripheral circuit gate electrode PGS may include a second conductive layer **132B**, a second intermediate layer **134B**, and a second metal layer **136B**. In some example embodiments, the second conductive layer **132B** may include Si, Ge, W, WN, Co, Ni, Al, Mo, Ru, Ti, TiN, Ta, TaN, Cu, or a combination thereof. The second intermediate layer **134B** and the second metal layer **136B** may each include TiN, TiSiN, W, tungsten silicide, or a combination thereof.

(45) In some example embodiments, the materials constituting or included in the second conductive layer **132B**, the second intermediate layer **134B**, and the second metal layer **136B** may be identical to the materials constituting or included in the first conductive layer **132A**, the first intermediate layer **134A**, and the first metal layer **136A** included in the cell pad structure **130** in the cell array area MCA, respectively. For example, the peripheral circuit gate electrode PGS may be simultaneously formed during a process of forming the cell pad structure **130**. In some example embodiments, because the cell pad structure **130** is formed at the same time as the peripheral circuit gate electrode PGS, the materials included in the second conductive layer **132B**, the second intermediate layer **134B**, and the second metal layer **136B** may be exactly the same as the respective materials included in the first conductive layer **132A**, the first intermediate layer **134A**, and the first metal layer **136A** included in the cell pad structure **130** in the cell array area MCA. In some example embodiments, the peripheral circuit gate electrode PGS is not formed at the same time as that of the bit line BL. Products and/or devices formed with such a process may have a different structure than products and/or devices formed with a typical process, insofar as the materials may be the same and/or the thickness may be the same.

(46) As shown in FIGS. **5** and **6**, the first metal layer **136A** included in the cell pad structure **130** may have a first height **h11** in the vertical direction Z, and the second metal layer **136B** included in the peripheral circuit gate electrode PGS may have a second height **h12** in the vertical direction Z. In some example embodiments, the second height **h12** may be substantially the same as the first height **h11**. For example, the first metal layer **136A** and the second metal layer **136B** may be formed during the same process by using the same material, and thus the first height **h11** of the first metal layer **136A** may be equal to the second height **h12** of the second metal layer **136B**.

(47) Alternatively or additionally, the bit line BL may have a third height **h13** in the vertical direction Z, and the third height **h13** may be different from the first height **h11** and the second height **h12**. Alternatively or additionally, the material constituting the bit line BL may be different from the material constituting the second metal layer **136B**. In some embodiments, the second metal layer **136B** included in the peripheral circuit gate electrode PGS may include tungsten (W), the first metal layer **136A** included in the cell pad structure **130** may include tungsten (W), and the bit line BL may include ruthenium (Ru). However, inventive concepts are not limited thereto.

(48) The peripheral circuit gate electrode PGS and both sidewalls of the gate capping pattern **142B** may be covered by insulation spacers **150B**. The insulation spacers **150B** may include an oxide layer, a nitride layer, or a combination thereof. The peripheral circuit transistor PTR and the insulation spacers **150B** may be covered by a passivation layer **146**, and a first interlayer insulation layer **148** may be disposed on the passivation layer **146** to fill the space between two adjacent peripheral circuit transistors PTR. A capping insulation layer **144B** may be disposed on the first interlayer insulation layer **148** and the passivation layer **146**.

(49) A contact plug CP may be formed in a contact hole CPH vertically penetrating through the first interlayer insulation layer **148** and the capping insulation layer **144B** in the peripheral circuit area PCA. The contact plug CP may include a conductive barrier film **162B** and a landing pad conductive layer **164B**, similar to the landing pads LP formed in the cell array area MCA. A metal silicide layer (not shown) may be provided between the second active area AC2 and the contact plug CP.

(50) A second etch stop layer **174** covering the contact plug CP may be disposed on the capping insulation layer **144B**. A second interlayer insulation layer **190** covering the capacitor structure **180**

may be disposed on the second etch stop layer **174**.

(51) As shown in FIG. 3, the outermost cell pad structure **130** from among the cell pad structures **130** may extend onto the boundary area BA. The cell pad structure **130** disposed on the boundary area BA may be referred to as a cell pad extension **130_E**. The cell pad extension **130_E** may include a first portion **130P1** and a second portion **130P2**. The first portion **130P1** may be disposed on the first active area AC1 and the device isolation layer **112**, and the second portion **130P2** may be disposed on the buffer layer **118**. Due to the thickness of the buffer layer **118**, the second portion **130P2** may have the top surface disposed at a higher level than the top surface of the first portion **130P1**.

(52) An edge conductive layer BL_E may be disposed on the second portion **130P2** of the cell pad extension **130_E**. The edge conductive layer BL_E may refer to or correspond to a portion of a bit line conductive layer **138** (refer to FIG. 16), which is for forming the bit line BL and remains after a process of patterning the bit line BL. However, in some example embodiments, a process for removing the edge conductive layer BL_E may be further performed. In this case, the edge conductive layer BL_E may be omitted.

(53) In general or typically, the peripheral circuit gate electrode PGS is formed to have the same stack configuration as that of the bit line BL. For example, the peripheral circuit gate electrode PGS is formed, such that the bit line BL and a metal layer included in the peripheral circuit gate electrode PGS include the same material and/or have the same height. However, in a process for patterning the bit line BL, it becomes difficult to precisely control the patterning process due to a step or a level difference of the top surface of the cell pad extension **130_E** disposed in the boundary area BA, and thus a process defect may occur.

(54) However, according to some example embodiments, the cell pad structure **130** and the peripheral circuit gate electrode PGS may be formed to have the same stack configuration. Therefore, a process defect due to a step or a level difference of the top surface of the cell pad extension **130_E** disposed in the boundary area BA may be prevented or reduced in likelihood of and/or impact from occurring. Alternatively or additionally, since a material included in the bit line BL may be selected independently from a material constituting the peripheral circuit gate electrode PGS, performance improvement or optimization of the semiconductor device **100** may be implemented.

(55) FIG. 7 is a cross-sectional view of a semiconductor device **10A** according to some example embodiments. FIG. 8 is an enlarged cross-sectional view of a portion CX1 of FIG. 7. FIG. 9 is an enlarged cross-sectional view of a portion CX2 of FIG. 7. In FIGS. 7 to 9, reference numerals same as those in FIGS. 1 to 6 denote the same elements.

(56) Referring to FIGS. 7 to 9, a peripheral circuit gate electrode PGSA may include the second conductive layer **132B**, the second intermediate layer **134B**, the second metal layer **136B**, and a third metal layer **138B** that are sequentially stacked on the gate dielectric layer **116**. The third metal layer **138B** may include ruthenium (Ru), tungsten (W), cobalt (Co), titanium (Ti), titanium nitride (TiN), or a combination thereof.

(57) In some example embodiments, the third metal layer **138B** may include the same material as that of the bit line BL. For example, the third metal layer **138B** and the bit line BL may be formed during the same process by using the same material, and thus a fourth height h14 of the third metal layer **138B** may be substantially the same as the third height h13 of the bit line BL.

(58) In some example embodiments, the second conductive layer **132B**, the second intermediate layer **134B**, and the second metal layer **136B** of the peripheral circuit gate electrode PGSA is formed by using the same material as the first cell pad structure **130**, and the third metal layer **138B** of the peripheral circuit gate electrode PGSA is formed by using the same material as the bit line BL. Therefore, a process defect due to a step or a level difference of the top surface of the cell pad extension **130_E** disposed in the boundary area BA may be prevented or reduced in likelihood of and/or impact from occurrence. Alternatively or additionally, since a material constituting the

peripheral circuit gate electrode PGSA may be selected independently from a material included in the bit line BL, performance improvement or optimization of the semiconductor device **100A** may be implemented.

(59) FIGS. **10A** to **21** are cross-sectional views showing a method of manufacturing the semiconductor device **100** according to some example embodiments. In detail, FIGS. **10A**, **12** to **18**, **19A**, **20**, and **21** are cross-sectional views corresponding to cross-sections taken along a line B1-B1' of FIG. **2**, and FIGS. **10B**, **11**, and **19B** are cross-sectional views corresponding to cross-sections taken along a line B2-B2' of FIG. **2**. In FIGS. **10A** to **21**, reference numerals same as those in FIGS. **1** to **9** denote the same elements.

(60) Referring to FIGS. **10A** and **10B**, a plurality of device isolation trenches **112T** may be formed in the cell array area MCA and the peripheral circuit area PCA of the substrate **110**, and the boundary trench **114T** may be formed in the boundary area BA of the substrate **110**.

(61) Thereafter, the device isolation layer **112** filling the device isolation trenches **112T** may be formed in the cell array area MCA and the peripheral circuit area PCA. As the device isolation layer **112** is formed, the first active areas AC1 are defined in the cell array area MCA of the substrate **110**, and the second active area AC2 is defined in the peripheral circuit area PCA.

(62) In some example embodiments, the device isolation layer **112** may be formed by using silicon oxide, silicon nitride, silicon oxynitride, or a combination thereof. In some example embodiments, the device isolation layer **112** may be formed as a double-layer structure including a silicon oxide layer and a silicon nitride layer, but inventive concepts are not limited thereto.

(63) Thereafter, the buried insulation layer **114A**, the insulation liner **114B**, and the gap-fill insulation layer **114C** are sequentially formed on the inner wall of the boundary trench **114T**, and upper portions of the buried insulation layer **114A**, the insulation liner **114B**, and the gap-fill insulation layer **114C** may be planarized, thereby forming the boundary structure **114**.

(64) In some example embodiments, the buried insulation layer **114A** may be formed through one or more of an atomic layer deposition (ALD) process, a chemical vapor deposition (CVD) process, a plasma enhanced CVD (PECVD) process, a low pressure CVD (LPCVD) process, etc. In some example embodiments, the process for forming the buried insulation layer **114A** may be performed at the same stage as at least some stages of the process for forming the device isolation layer **112**, but inventive concepts are not limited thereto. In some example embodiments, the process for forming the buried insulation layer **114A** may be separately performed after the process of forming the device isolation layer **112**.

(65) In some example embodiments, the insulation liner **114B** may be formed by using silicon nitride through an ALD process, a CVD process, a PECVD process, an LPCVD process, etc. The gap-fill insulation layer **114C** may be formed to fill the boundary trench **114T** on the insulation liner **114B**. The gap-fill insulation layer **114C** may be formed to have a thickness sufficient to completely fill the remaining portion inside the boundary trench **114T**.

(66) In some example embodiments, the gap-fill insulation layer **114C** may include a silicon oxide such as Tonen Silazene (TOSZ), undoped silicate glass (USG), boro-phospho-silicate glass (BPSG), phosphosilicate glass (PSG), flowable oxide (FOX), plasma enhanced deposition of tetra-ethyl-ortho-silicate (PE-TEOS), or fluoride silicate glass (FSG).

(67) Referring to FIG. **11**, a mask pattern (not shown) may be formed on the substrate **110**, and a portion of the cell array area MCA of the substrate **110** may be removed by using the mask pattern as an etch mask, thereby forming the word line trench **120T**.

(68) The word line trench **120T** may be disposed to extend from the cell array area MCA to a portion of the boundary area BA. For example, the mask pattern for forming the word line trench **120T** may be formed by using a double patterning technique (DPT) or a quadruple patterning technique (QPT), but inventive concepts are not limited thereto.

(69) Thereafter, the gate dielectric layer **122**, the gate electrode **124**, and the capping insulation layer **126** may be sequentially formed in the word line trench **120T**.

(70) For example, the gate dielectric layer **122** may be conformally disposed on the inner wall of the word line trench **120T**. The gate electrode **124** may be formed by filling the word line trench **120T** with a conductive layer (not shown) and then etching back the upper portion of the conductive layer to expose the upper portion of the word line trench **120T** again. The capping insulation layer **126** may be formed by filling the remaining portion of the word line trench **120T** with an insulation material and planarizing the insulation material until the top surface of the buried insulation layer **114A** is exposed.

(71) Referring to FIG. **12**, the buffer layer **118** may be formed on the cell array area MCA and the boundary area BA. The buffer layer **118** may cover the top surface of the first active area AC1 in the cell array area MCA, and the top surface of the second active area AC2 may not be covered by the buffer layer **118** in the peripheral circuit area PCA.

(72) Thereafter, the gate dielectric layer **116** may be formed on the substrate **110** in the peripheral circuit area PCA. The gate dielectric layer **116** may be formed through one or more of a thermal oxidation process, an ALD process, a CVD process, a PECVD process, an LPCVD process, etc.

(73) Thereafter, a portion of the buffer layer **118** covering the cell array area MCA may be removed, thereby leaving the buffer layer **118** on the boundary area BA. The buffer layer **118** may cover the first active area AC1 and the top surface of the device isolation layer **112** in edge areas of the cell array area MCA and may extend onto the boundary structure **114**.

(74) In some example embodiments, a recess process may be performed on the top surface of the device isolation layer **112** exposed in the cell array area MCA, such that the top surface of the first active area AC1 is located at a higher level than the top surface of the device isolation layer **112** and a portion of the sidewall of the first active area AC1 is exposed. However, inventive concepts are not limited thereto.

(75) Referring to FIG. **13**, a conductive layer **132** may be formed on the buffer layer **118** in the cell array area MCA and on the gate dielectric layer **116** and the device isolation layer **112** in the peripheral circuit area PCA. In some example embodiments, the conductive layer **132** may include Si, Ge, W, WN, Co, Ni, Al, Mo, Ru, Ti, TiN, Ta, TaN, Cu, or a combination thereof. For example, the conductive layer **132** may include polysilicon such as doped polysilicon.

(76) Thereafter, an intermediate layer **134** may be formed on the conductive layer **132**, and a metal layer **136** may be formed on the intermediate layer **134**. The intermediate layer **134** and the metal layer **136** may be formed on the entire areas of the cell array area MCA and the peripheral circuit area PCA. In some example embodiments, the intermediate layer **134** and the metal layer **136** may include TiN, TiSiN, W, tungsten silicide, or a combination thereof.

(77) Referring to FIG. **14**, a mask pattern (not shown) may be formed on the metal layer **136**, and the metal layer **136**, the intermediate layer **134**, and the conductive layer may be patterned in the cell array area MCA by using the mask pattern as an etching mask, thereby forming the cell pad structures **130**.

(78) In some example embodiments, the cell pad structures **130** may have a regular grid arrangement and/or matrix arrangement in which the cell pad structures **130** are arranged to be spaced apart from one another in the first horizontal direction X and the second horizontal direction Y. The metal layer **136** may remain on the peripheral circuit area PCA.

(79) The outermost cell pad structure **130** from among the cell pad structures **130** may extend onto the boundary area BA. The cell pad structure **130** disposed on the boundary area BA may be referred to as a cell pad extension **130_E**. The cell pad extension **130_E** may include a first portion **130P1** and a second portion **130P2**. The first portion **130P1** may be disposed on the first active area AC1 and the device isolation layer **112**, and the second portion **130P2** may be disposed on the buffer layer **118**. Due to the thickness of the buffer layer **118**, the second portion **130P2** may have the top surface disposed at a higher level than the top surface of the first portion **130P1**.

(80) Thereafter, the insulation pattern **152** surrounding the sidewalls of the cell pad structures **130** may be formed. The insulation pattern **152** may be formed by using silicon nitride.

(81) Referring to FIG. 15, the insulation layer **154** may be formed on the cell pad structures **130**, the top surface of the insulation pattern **152**, and on the metal layer **136**. The insulation layer **154** may be formed by using silicon nitride.

(82) Thereafter, a mask pattern (not shown) may be formed on the insulation layer **154**, and some of the cell pad structures **130** may be removed to re-expose the first active area AC1 of the substrate **110**. Thereafter, the upper portion of the exposed substrate **110** may be further removed, thereby forming a direct contact hole DCH.

(83) Thereafter, the direct contact spacer DCS may be formed on the inner wall of the direct contact hole DCH. For example, the direct contact spacer DCS may be formed by using silicon nitride or silicon oxide.

(84) A conductive layer (not shown) may be formed inside the direct contact hole DCH, and the upper portion of the conductive layer may be etched back until the top surface of the insulation layer **154** is exposed, thereby forming the direct contact DC inside the direct contact hole DCH.

(85) Referring to FIG. 16, the bit line conductive layer **138** covering the direct contact DC and the insulation layer **154** may be formed. The bit line conductive layer **138** may include at least one of ruthenium (Ru), tungsten (W), cobalt (Co), titanium (Ti), and titanium nitride (TiN).

(86) In some example embodiments, the bit line conductive layer **138** may be formed by using a material different from a material included in the metal layer **136**. However, inventive concepts are not limited thereto, and the bit line conductive layer **138** may be formed by using the same material as the material included in the metal layer **136**.

(87) Referring to FIG. 17, the insulation layer **154** and the bit line conductive layer **138** may be removed from the peripheral circuit area PCA and the boundary area BA.

(88) Thereafter, a first insulation capping layer **142** may be formed on the metal layer **136** in the peripheral circuit area PCA and on the bit line conductive layer **138** in the cell array area MCA.

(89) Referring to FIG. 18, a mask pattern (not shown) may be formed on the first insulation capping layer **142**, and the first insulation capping layer **142**, the metal layer **136**, the intermediate layer **134**, and the conductive layer **132** may be patterned in the peripheral circuit area PCA by using the mask pattern, thereby forming the gate capping pattern **142B** and the peripheral circuit gate electrode PGS.

(90) In some example embodiments, the peripheral circuit gate electrode PGS may include the second conductive layer **132B**, the second intermediate layer **134B**, and the second metal layer **136B** sequentially arranged on the gate dielectric layer **116**.

(91) Thereafter, an insulation spacer **150B** covering the sidewall of the peripheral circuit gate electrode PGS may be formed. The insulation spacer **150B** may be formed by using silicon nitride.

(92) In the process of forming the insulation spacer **150B**, a spacer **150_E** may also be disposed on the sidewall of the cell pad extension **130_E** disposed in the boundary area BA.

(93) Thereafter, a passivation layer **146** covering the gate capping pattern **142B** and sidewalls of the peripheral circuit gate electrode PGS is formed in the peripheral circuit area PCA. An insulation layer (not shown) may be formed on the passivation layer **146** to completely cover the gate capping pattern **142B** and the peripheral circuit gate electrode PGS, and the upper portion of the insulation layer may be planarized until the top surface of the gate capping pattern **142B** is exposed, thereby forming the first interlayer insulation layer **148**.

(94) Referring to FIGS. 19A and 19B, a second insulation capping layer **144** may be formed on the first insulation capping layer **142** in the cell array area MCA and on the first interlayer insulation layer **148** in the peripheral circuit area PCA.

(95) Thereafter, the second insulation capping layer **144**, the first insulation capping layer **142**, and the bit line conductive layer **138** may be patterned in the cell array area MCA, thereby forming the insulation capping structures **140** and the bit lines BL.

(96) In the process of forming the bit line BL, an upper portion of the direct contact spacer DCS disposed inside the direct contact hole DCH may be removed at the same time, and thus the top

surface of the direct contact spacer DCS may be located at a level lower than that of the top surface of the direct contact DC.

(97) In the process of forming the bit line BL, a portion of the bit line conductive layer **138** may remain on the boundary area BA, and the portion may be referred to as the edge conductive layer BL_E.

(98) Thereafter, the bit line spacer **150A** may be formed on the sidewall of a bit line structure BLS, and the insulation fences **156** may be formed between the bit lines BL.

(99) Referring to FIG. **20**, the second insulation capping layer **144** and the first interlayer insulation layer **148** are etched in the peripheral circuit area PCA, thereby forming a plurality of contact holes CPH exposing the second active areas AC2 of the substrate **110**. Thereafter, the insulation layer **154** exposed between the bit lines BL is removed in the cell array area MCA, thereby exposing the top surface of the cell pad structure **130**.

(100) Thereafter, a conductive barrier film **162** and a conductive layer **164** covering the exposed surface of the substrate **110** in the cell array area MCA and the peripheral circuit area PCA are formed. By patterning the conductive barrier film **162** and the conductive layer **164**, the landing pads LP including the conductive barrier film **162A** and the landing pad conductive layer **164A** are formed in the cell array area MCA, and a plurality of contact plugs CP including the conductive barrier film **162B** and the landing pad conductive layer **164B** are formed in the peripheral circuit area PCA.

(101) Referring now to FIG. **21**, the insulation pattern **166** covering the landing pads LP may be formed in the cell array area MCA, and the second etch stop layer **174** covering the contact plugs CP may be formed in the peripheral circuit area PCA.

(102) Thereafter, the first etch stop layer **172** may be formed on the cell array area MCA.

(103) The lower electrodes **182**, which penetrate through the first etch stop layer **172** and are connected to the landing pads LP, may be formed, and the capacitor dielectric layer **184** and the upper electrode **186** may be sequentially formed on the sidewalls of the lower electrodes **182**.

(104) Thereafter, the second interlayer insulation layer **190** covering the upper electrode **186** may be formed on the cell array area MCA and the peripheral circuit area PCA.

(105) The semiconductor device **100** may be completed by performing the above-described method.

(106) In general or typically, the peripheral circuit gate electrode PGS is formed to have the same stack configuration as that of the bit line BL. For example, the peripheral circuit gate electrode PGS is formed, such that the bit line BL and a metal layer included in the peripheral circuit gate electrode PGS include the same material and/or have the same height. However, in a process for patterning the bit line BL, it becomes difficult to precisely control a patterning process due to a step or a level difference of the top surface of the cell pad extension **130_E** disposed in the boundary area BA, and thus a process defect may occur.

(107) However, according to some example embodiments, the cell pad structure **130** and the peripheral circuit gate electrode PGS may be formed to have the same stack configuration. Therefore, a process defect due to a step or a level difference of the top surface of the cell pad extension **130_E** disposed in the boundary area BA may be prevented or reduced in likelihood of and/or impact from occurrence. Alternatively or additionally, since a material included in the bit line BL may be selected independently from a material constituting the peripheral circuit gate electrode PGS, performance improvement and/or flexibility and/or optimization of the semiconductor device **100** may be implemented.

(108) In other embodiments, in the process described with reference to FIG. **15**, the insulation layer **154** formed on the peripheral circuit area PCA may be removed, and then the bit line conductive layer **138** may be formed directly on the metal layer **136**. In this case, the semiconductor device **100A** described with reference to FIGS. **7** to **9** may be formed.

(109) When the terms “about” or “substantially” are used in this specification in connection with a

numerical value, it is intended that the associated numerical value includes a manufacturing or operational tolerance (e.g., $\pm 10\%$) around the stated numerical value. Moreover, when the words “generally” and “substantially” are used in connection with geometric shapes, it is intended that precision of the geometric shape is not required but that latitude for the shape is within the scope of the disclosure. Moreover, when the words “generally” and “substantially” are used in connection with material composition, it is intended that exactitude of the material is not required but that latitude for the material is within the scope of the disclosure.

(110) Further, regardless of whether numerical values or shapes are modified as “about” or “substantially,” it will be understood that these values and shapes should be construed as including a manufacturing or operational tolerance (e.g., $\pm 10\%$) around the stated numerical values or shapes. Thus, while the term “same,” “identical,” or “equal” is used in description of example embodiments, it should be understood that some imprecisions may exist. Thus, when one element or one numerical value is referred to as being the same as another element or equal to another numerical value, it should be understood that an element or a numerical value is the same as another element or another numerical value within a desired manufacturing or operational tolerance range (e.g., $\pm 10\%$).

(111) While inventive concepts have been particularly shown and described with reference to embodiments thereof, it will be understood that various changes in form and details may be made therein without departing from the spirit and scope of the following claims. Furthermore example embodiments are not necessarily mutually exclusive. For example, some example embodiments may include one or more features described with reference to one or more figures, and may also include one or more other features described with reference to one or more other figures.

Claims

1. A semiconductor device comprising: a substrate comprising a cell array area, a peripheral circuit area, a plurality of first active areas defined in the cell array area, and at least one second active area defined in the peripheral circuit area; a plurality of bit lines in the cell array area of the substrate and extending in a first direction; a plurality of cell pad structures between the plurality of bit lines and each comprising a first conductive layer, a first intermediate layer, and a first metal layer that are sequentially arranged on a top surface of a respective one of the plurality of first active areas; and a peripheral circuit gate electrode on the peripheral circuit area of the substrate and comprising a second conductive layer, a second intermediate layer, and a second metal layer that are sequentially arranged on the at least one second active area.
2. The semiconductor device of claim 1, wherein the first conductive layer comprises a same first material as the material included in the second conductive layer, the first intermediate layer comprises a same second material as the material included in the second intermediate layer, and the first metal layer comprises a same third material as the material included in the second metal layer.
3. The semiconductor device of claim 1, wherein the first conductive layer covers a top surface and side surfaces of each of the first active areas.
4. The semiconductor device of claim 1, further comprising: a bit line contact between the bit lines and the first active areas; a bit line contact spacer between the bit line contact and a respective one of the plurality of cell pad structures; and bit line spacers on sidewalls of the plurality of bit lines.
5. The semiconductor device of claim 4, wherein the bit line contact comprises a metal material, and the bit line contact contacts top surfaces of the first active areas.
6. The semiconductor device of claim 4, wherein sidewalls of the first conductive layer of the plurality of cell pad structures contact the bit line contact spacer, and sidewalls of the first metal layer of the plurality of cell pad structures contact the bit line spacers.
7. The semiconductor device of claim 1, wherein the substrate further comprises a boundary area between the cell array area and the peripheral circuit area, and the semiconductor device further

comprises: a boundary structure in a boundary trench extending into the boundary area, the boundary structure comprising an insulation material; and a buffer layer on the boundary structure.

8. The semiconductor device of claim 7, wherein at least one of the cell pad structures extends onto the boundary structure.

9. The semiconductor device of claim 8, wherein the at least one of the cell pad structures comprises a first portion and a second portion, the first portion is on the first active areas, and the second portion is on the buffer layer.

10. The semiconductor device of claim 1, wherein the first metal layer has a first height in a vertical direction, the second metal layer has a second height in the vertical direction, and the second height is same as the first height.

11. The semiconductor device of claim 10, wherein the bit lines have a third height in the vertical direction, and the third height is different from the first height and is different from the second height.

12. The semiconductor device of claim 1, wherein the peripheral circuit gate electrode further comprises a third metal layer disposed on the second metal layer, and the third metal layer comprises a same material as the material included in the bit lines.

13. The semiconductor device of claim 12, wherein the bit lines have a third height in a vertical direction, the third metal layer has a fourth height in the vertical direction, and the fourth height is same as the third height.

14. A semiconductor device comprising: a substrate comprising a cell array area, a boundary area, a peripheral circuit area, a plurality of first active areas defined in the cell array area, and at least one second active area defined in the peripheral circuit area; a plurality of bit lines in the cell array area of the substrate and extending in a first direction; a plurality of cell pad structures arranged between two adjacent bit lines from among the plurality of bit lines and each comprising a first conductive layer and a first metal layer that are sequentially arranged on a top surface of a respective one of the plurality of the first active area; and a peripheral circuit gate electrode on the peripheral circuit area of the substrate and comprising a second conductive layer and a second metal layer that are sequentially arranged on the at least one second active area, wherein a first height of the cell pad structures is same as a second height of the peripheral circuit gate electrode.

15. The semiconductor device of claim 14, further comprising: a bit line contact disposed between the bit lines and the first active areas; a bit line contact spacer disposed between the bit line contact and a respective one of the plurality of cell pad structures; and bit line spacers arranged on sidewalls of the bit lines.

16. The semiconductor device of claim 15, wherein sidewalls of the first conductive layer of the plurality of cell pad structures contact the bit line contact spacer, and sidewalls of the first metal layer of the cell pad structure contact the bit line spacers.

17. The semiconductor device of claim 14, wherein the first conductive layer comprises a same first material as the material included in the second conductive layer, and the first metal layer comprises a same second material as the material included in the second metal layer.

18. The semiconductor device of claim 14, further comprising: a boundary structure in a boundary trench extending into the boundary area, the boundary structure comprising an insulation material; and a buffer layer on the boundary structure, wherein at least one of the cell pad structures extends onto the boundary structure.

19. The semiconductor device of claim 14, wherein the first metal layer has a first height in a vertical direction, the second metal layer has a second height in the vertical direction, and the second height is same as the first height.

20. A semiconductor device comprising: a substrate comprising a cell array area, a boundary area, a peripheral circuit area, a plurality of first active areas defined in the cell array area, and at least one second active area defined in the peripheral circuit area; a plurality of bit lines in the cell array area of the substrate and extending in a first direction; a bit line contact disposed between the bit lines

and the first active areas and electrically connecting the bit lines to the first active areas; a bit line contact spacer surrounding sidewalls of the bit line contact; a plurality of cell pad structures between two adjacent bit lines from among the plurality of bit lines and each comprising a first conductive layer, a first intermediate layer, and a first metal layer that are sequentially arranged on a top surface of a respective one of the plurality of first active areas; a plurality of landing pads respectively arranged on the cell pad structures; and a peripheral circuit gate electrode on the peripheral circuit area of the substrate and comprising a second conductive layer, a second intermediate layer, and a second metal layer that are sequentially arranged on the at least one second active area, wherein the second metal layer comprises a same material as the material included in the first metal layer.
