

SEMICONDUCTOR MEMORY DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This patent application claims priority to Korean Patent Application No. 10-2021-0108248, filed on 17 August 2021, in the Korean Intellectual Property Office, the entire contents of which are hereby incorporated by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to a semiconductor memory device, and in particular, to a semiconductor memory device including vertical channel transistors and a method of fabricating the same.

BACKGROUND

[0003] As a design rule of a semiconductor device decreases, it is possible to increase an integration density and an operation speed of the semiconductor device, but new technologies are required to improve or maintain a production yield. Thus, semiconductor devices with vertical channel transistors have been suggested to increase an integration density of a semiconductor device and improve resistance and current driving characteristics of the transistor.

SUMMARY

[0004] According to an embodiment, a semiconductor memory device may include a bit line, a channel pattern on the bit line, the channel pattern including a horizontal channel portion, which is provided on the bit line, and a vertical channel portion, which is vertically extended from the horizontal channel portion, a word line provided on the channel pattern to cross the bit line, the word line including a horizontal portion, which is provided on the horizontal channel portion, and a vertical portion, which is vertically extended from the horizontal portion to face the vertical channel portion, and a gate insulating pattern provided between the channel pattern and the word line.

[0005] According to an embodiment, a semiconductor memory device may include a bit line extending in a first direction, a channel pattern on the bit line, the channel pattern including first and second vertical channel portions, which are opposite to each other, and a horizontal channel portion, which connects the first and second vertical channel portions to each other, first and

second word lines, which are provided on the horizontal channel portion to be symmetric with respect to each other, each of the first and second word lines including a horizontal portion, which is provided on the horizontal channel portion, and a vertical portion, which is vertically extended from the horizontal portion to face the vertical channel portion, and a gate insulating pattern provided between the first and second word lines and the channel pattern.

[0006] According to an embodiment, a semiconductor memory device may include a peripheral circuit structure including peripheral circuits on a semiconductor substrate and a lower insulating layer covering the peripheral circuits, a plurality of bit lines provided on the peripheral circuit structure and extended in a first direction, a mold insulating pattern having a plurality of trenches, which are extended in a second direction to cross the bit lines, channel patterns, which are spaced apart from each other in the second direction in each of the trenches, each of the channel patterns including first and second vertical channel portions, which are opposite to each other, and a horizontal channel portion, which connects the first and second vertical channel portions to each other, a first word line and a second word line, which are extended in the second direction in each of the trenches, each of the first and second word lines including a horizontal portion and a vertical portion, which is extended from the horizontal portion in a third direction perpendicular to the first and second directions, a first spacer on the first word line, a second spacer on the second word line, a gate insulating pattern disposed between the channel patterns and the first and second word lines and extended in the second direction, landing pads disposed on the first and second vertical channel portions of the channel patterns, respectively, and data storage patterns disposed on the landing pads, respectively.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Features will become apparent to those of skill in the art by describing in detail exemplary embodiments with reference to the attached drawings, in which:

[0008] FIG. 1 is a block diagram illustrating a semiconductor memory device including a semiconductor element according to an embodiment.

[0009] FIG. 2 is a perspective view schematically illustrating a semiconductor memory device according to an embodiment.

[0010] FIG. 3 is a plan view illustrating a semiconductor memory device according to an embodiment.

[0011] FIGS. 4A and 4B are sectional views illustrating cross-sections taken along lines A-A', B-B', C-C', D-D', and E-E' of FIG. 3.

[0012] FIGS. 5A, 5B, 5C, 5D, and 5E are enlarged sectional views, each of which illustrates portion 'P' of FIG. 4A.

[0013] FIGS. 6A and 6B are sectional views illustrating cross-sections taken along the lines A-A', B-B', C-C', and D-D' of FIG. 3.

[0014] FIG. 7 is a plan view illustrating a semiconductor memory device according to an embodiment.

[0015] FIG. 8 is a perspective view schematically illustrating a semiconductor memory device according to an embodiment.

[0016] FIGS. 9A and 9B are sectional views illustrating cross-sections taken along the lines A-A', B-B', C-C', D-D', and E-E' of FIG. 3.

[0017] FIG. 10 is a perspective view schematically illustrating a semiconductor memory device according to an embodiment.

[0018] FIGS. 11A and 11B are sectional views illustrating cross-sections taken along the lines A-A', B-B', C-C', and D-D' of FIG. 3.

[0019] FIGS. 12A to 19A are plan views illustrating stages in a method of fabricating a semiconductor memory device, according to an embodiment.

[0020] FIGS. 12B to 19B, 12C to 19C, 20A to 23A, and 20B to 23B are sectional views illustrating stages in a method of fabricating a semiconductor memory device according to an embodiment.

DETAILED DESCRIPTION

[0021] FIG. 1 is a block diagram illustrating a semiconductor memory device including a semiconductor element according to an embodiment.

[0022] Referring to FIG. 1, a semiconductor memory device may include a memory cell array 1, a row decoder 2, a sense amplifier 3, a column decoder 4, and a control logic 5.

[0023] The memory cell array 1 may include a plurality of memory cells MC, which are two-dimensionally or three-dimensionally arranged. Each of the memory cells MC may be provided between and connected to a word line WL and a bit line BL, which are disposed to cross each other.

[0024] Each of the memory cells MC may include a selection element TR and a data storage element DS, which are electrically connected to each other in series. The selection element TR may be provided between and connected to the data storage element DS and the word line WL, and the data storage element DS may be connected to the bit line BL through the selection element TR. The selection element TR may be a field effect transistor (FET), and the data storage element DS may be realized using at least one of, e.g., a capacitor, a magnetic tunnel junction pattern, or a variable resistor. As an example, the selection element TR may include a transistor whose gate electrode is connected to the word line WL and whose drain/source terminals are connected to the bit line BL and the data storage element DS, respectively.

[0025] The row decoder 2 may be configured to decode address information, which is input from the outside, and to select one of the word lines WL of the memory cell array 1, based on the decoded address information. The address information decoded by the row decoder 2 may be provided to a row driver, and in this case, the row driver may provide respective voltages to the selected one of the word lines WL and the unselected ones of the word lines WL, in response to the control of a control circuit.

[0026] The sense amplifier 3 may be configured to sense, amplify, and output a difference in voltage between one of the bit lines BL, which is selected based on address information decoded by the column decoder 4, and a reference bit line.

[0027] The column decoder 4 may be used as a data transmission path between the sense amplifier 3 and an external device (e.g., a memory controller). The column decoder 4 may be configured to decode address information, which is input from the outside, and to select one of the bit lines BL, based on the decoded address information.

[0028] The control logic 5 may be configured to generate control signals, which are used to control data-writing or data-reading operations on the memory cell array 1.

[0029] FIG. 2 is a perspective view schematically illustrating a semiconductor memory device according to an embodiment.

[0030] Referring to FIG. 2, a semiconductor memory device may include a peripheral circuit structure PS on a semiconductor substrate 100 and a cell array structure CS on the peripheral circuit structure PS.

[0031] The peripheral circuit structure PS may include core and peripheral circuits, which are formed on the semiconductor substrate 100. The core and peripheral circuits may include the row and column decoders 2 and 4, the sense amplifier 3, and the control logics 5 described with reference to FIG. 1. The peripheral circuit structure PS may be provided between the semiconductor substrate 100 and the cell array structure CS, in a third direction D3 perpendicular to a top surface of the semiconductor substrate 100.

[0032] The cell array structure CS may include the bit lines BL, the word lines WL, and the memory cells MC therebetween (e.g., see FIG. 1). The memory cells MC (e.g., see FIG. 1) may be two- or three-dimensionally arranged on a plane, which are extended in first and second directions D1 and D2 that are not parallel to each other. Each of the memory cells MC (e.g., see FIG. 1) may include the selection element TR and the data storage element DS, as described above.

[0033] In an embodiment, a vertical channel transistor (VCT) may be provided as the selection element TR of each memory cell MC (e.g., see FIG. 1). The vertical channel transistor may mean a transistor whose channel region is extended in a direction perpendicular to the top surface of the semiconductor substrate 100 (i.e., in the third direction D3). In addition, a capacitor may be provided as the data storage element DS of each memory cell MC (e.g., see FIG. 1).

[0034] FIG. 3 is a plan view illustrating a semiconductor memory device according to an embodiment. FIGS. 4A and 4B are sectional views illustrating cross-sections taken along lines A-A', B-B', C-C', D-D', and E-E' of FIG. 3. FIGS. 5A, 5B, 5C, 5D, and 5E are enlarged sectional views, each of which illustrates portion 'P' of FIG. 4A.

[0035] Referring to FIGS. 3, 4A, and 4B, a semiconductor memory device according to an embodiment may include the peripheral circuit structure PS and the cell array structure CS.

[0036] The peripheral circuit structure PS may include core and peripheral circuits SA and PC, which are integrated on the top surface of the semiconductor substrate 100, a peripheral circuit insulating layer ILD, which is provided to cover the core and peripheral circuits SA and PC, peripheral contact plugs PCT, and peripheral circuit lines PCL.

[0037] In detail, the semiconductor substrate 100 may be, e.g., a single-crystalline silicon substrate. The semiconductor substrate 100 may include a cell array region CAR and a peripheral circuit region PCR.

[0038] The core circuit SA including the sense amplifier 3 (e.g., see FIG. 1) may be provided on the cell array region CAR of the semiconductor substrate 100, and the peripheral circuits PC, e.g., a word line driver and the control logic 5 (e.g., see FIG. 1), may be provided on the peripheral circuit region PCR of the semiconductor substrate 100.

[0039] The core and peripheral circuits SA and PC may include NMOS and PMOS transistors, which are integrated on the semiconductor substrate 100. The core and peripheral circuits SA and PC may be electrically connected to the bit lines BL and the word lines WL through the peripheral circuit lines PCL and the peripheral circuit contact plugs PCT. The sense amplifiers may be electrically connected to the bit lines BL, and each of the sense amplifiers may be configured to amplify and output a difference in voltage level between voltages which are sensed by a pair of the bit lines BL.

[0040] The peripheral circuit insulating layer ILD may be provided on the semiconductor substrate 100 to cover the core and peripheral circuits SA and PC, the peripheral circuit lines PCL, and the peripheral circuit contact plugs PCT. The peripheral circuit insulating layer ILD may have a substantially flat top surface. The peripheral circuit insulating layer ILD may include a plurality of vertically-stacked insulating layers. For example, the peripheral circuit insulating layer ILD may include a silicon oxide layer, a silicon nitride layer, a silicon oxynitride layer, and/or a low-k dielectric layer.

[0041] The cell array structure CS may be provided on the peripheral circuit insulating layer ILD. The cell array structure CS may include a plurality of the bit lines BL, channel patterns CP, first and second word lines WL1 and WL2, a gate insulating pattern Gox (FIG. 5B), and data storage patterns DSP.

[0042] The bit lines BL may be provided on the peripheral circuit insulating layer ILD to extend, e.g., lengthwise, in the first direction D1 and may be spaced apart from each other in the second direction D2. The bit lines BL may have a first width W1 in the second direction D2, and the first width W1 may range from about 1 nm to about 50 nm.

[0043] The bit lines BL may be formed of or include at least one of, e.g., doped polysilicon, metallic materials, conductive metal nitrides, conductive metal silicides, conductive metal oxides, or combinations thereof. The bit lines BL may be formed of at least one of, e.g., doped polysilicon, Al, Cu, Ti, Ta, Ru, W, Mo, Pt, Ni, Co, TiN, TaN, WN, NbN, TiAl, TiAlN, TiSi, TiSiN, TaSi, TaSiN, RuTiN, NiSi, CoSi, IrOx, RuOx, or combinations thereof. Each of the bit lines BL may have a single- or multi-layered structure that is formed of at least one of the afore-described materials. In an embodiment, the bit lines BL may be formed of or include at least one of two- and three-dimensional materials and may be formed of or include, e.g., a carbon-based two-dimensional material (e.g., graphene), a carbon-based three-dimensional material (e.g., carbon nanotube), or combinations thereof.

[0044] The bit lines BL may be connected to the peripheral circuit lines PCL through lower contact plugs LCT. Furthermore, lower conductive patterns LCP, which are located at the same level as the bit lines BL, may be disposed on the peripheral circuit region PCR. The lower conductive patterns LCP may be connected to the peripheral circuit lines PCL through the lower contact plugs LCT. The lower conductive patterns LCP may be formed of or include the same conductive material as the bit lines BL.

[0045] Lower insulating patterns 111 may be disposed between the bit lines BL and the peripheral circuit lines PCL and between the lower conductive patterns LCP and the peripheral circuit lines PCL to enclose the lower contact plugs LCT, respectively.

[0046] A first insulating pattern 121 may be disposed between the bit lines BL. The first insulating pattern 121 may be formed of or include at least one of, e.g., silicon oxide, silicon nitride, silicon oxynitride, and/or low-k dielectric materials.

[0047] Shielding structures SS may be respectively provided between the bit lines BL and may be extended in the first direction D1 and parallel to each other. The shielding structures SS may be formed of or include at least one of conductive materials (e.g., metallic materials). The shielding structures SS may be provided in the first insulating pattern 121, and top surfaces of the shielding structures SS may be located at a level lower than top surfaces of the bit lines BL.

[0048] In an embodiment, the shielding structures SS may be formed of a conductive material, and an air gap or void may be formed in the shielding structure SS. In another embodiment, air gaps, instead of the shielding structures SS, may be defined in the first insulating pattern 121.

[0049] A mold insulating pattern 125 may be disposed on the first insulating pattern 121 and the bit lines BL. The mold insulating pattern 125 may define trenches T (e.g., see FIG. 14A), which are extended in the second direction D2 to cross the bit lines BL and are spaced apart from each other in the first direction D1. The mold insulating pattern 125 may cover top surfaces of the lower conductive patterns LCP, on the peripheral circuit region PCR. The mold insulating pattern 125 may be formed of or include at least one of, e.g., silicon oxide, silicon nitride, silicon oxynitride, and/or low-k dielectric materials.

[0050] The channel patterns CP may be disposed on the bit lines BL. The channel patterns CP on each bit line BL may be spaced apart from each other in the first direction D1 by the mold insulating pattern 125. The channel patterns CP in each trench of the mold insulating pattern 125 may be spaced apart from each other in the second direction D2. That is, the channel patterns CP may be two-dimensionally arranged in two different directions (e.g., in the first and second directions D1 and D2).

[0051] As illustrated in FIG. 3, each of the channel patterns CP may have a first length L1 in the first direction D1 and may have a second width W2, which is substantially equal to or larger than the first width W1 of the bit lines BL, in the second direction D2, e.g., each of the channel patterns CP may completely overlap and extend beyond a corresponding bit line BL in the

second direction D2 (FIG. 4B). A distance between the channel patterns CP in the first direction D1 may be different from the first length L1 of the channel pattern CP in the first direction D1. As an example, the distance between the channel patterns CP in the first direction D1 may be smaller than the first length L1 of the channel pattern CP in the first direction D1. As another example, the distance between the channel patterns CP in the first direction D1 may be substantially equal to the first length L1 of the channel pattern CP in the first direction D1. A distance between the channel patterns CP in the second direction D2 may be substantially equal to or smaller than the second width W2 of the channel pattern CP.

[0052] In more detail, referring to FIG. 5A, each of the channel patterns CP may include a horizontal channel portion HCP, which is disposed on the bit line BL, and first and second vertical channel portions VCP1 and VCP2, which are vertically extended from the horizontal channel portion HCP and are opposite to each other in the first direction D1. Each of the first and second vertical channel portions VCP1 and VCP2 may have an outer side surface, which is in contact with the mold insulating pattern 125, and an inner side surface, which is opposite to the outer side surface, and the inner side surfaces of the first and second vertical channel portions VCP1 and VCP2 may face each other in the first direction D1. In addition, the channel patterns CP, which are adjacent to each other in the first direction D1, may be provided such that the outer side surfaces of the first and second vertical channel portions VCP1 and VCP2 thereof are opposite to each other.

[0053] Each of the channel patterns CP may have the first length L1 in the first direction D1. The first length L1 may be larger than the distance between the channel patterns CP, which are adjacent to each other in the first direction D1.

[0054] The first and second vertical channel portions VCP1 and VCP2 may have a vertical length in the third direction D3, which is perpendicular to the top surface of the semiconductor substrate 100, and may have a width in the first direction D1. For example, the vertical length of the first and second vertical channel portions VCP1 and VCP2 may be about 2 to 10 times the width thereof. The widths of the first and second vertical channel portions VCP1 and VCP2 in the first direction D1 may be in the range of several nanometers to several tens of nanometers.

For example, the widths of the first and second vertical channel portions VCP1 and VCP2 may range from 1 nm to 30 nm, e.g., from 1 nm to 10 nm.

[0055] The horizontal channel portions HCP of the channel patterns CP may be in direct contact with the top surfaces of the bit lines BL. A thickness of the horizontal channel portion HCP on the top surface of the bit line BL may be substantially equal to thicknesses, e.g., widths in the first direction D1, of the first and second vertical channel portions VCP1 and VCP2 on a side surface of the mold insulating pattern 125.

[0056] In each of the channel patterns CP, the horizontal channel portion HCP may include a common source/drain region, an upper end of the first vertical channel portion VCP1 may include a first source/drain region, and an upper end of the second vertical channel portion VCP2 may include a second source/drain region. The first vertical channel portion VCP1 may include a first channel region between the first source/drain region and the common source/drain region, and the second vertical channel portion VCP2 may include a second channel region between the second source/drain region and the common source/drain region. In an embodiment, the first channel region of the first vertical channel portion VCP1 may be controlled by the first word line WL1, and the second channel region of the second vertical channel portion VCP2 may be controlled by the second word line WL2.

[0057] A portion of the channel pattern CP may be located between the first and second word lines WL1 and WL2. The horizontal channel portion HCP of the channel pattern CP may electrically connect the first and second vertical channel portions VCP1 and VCP2 to a corresponding one of the bit lines BL. That is, in the semiconductor memory device according to an embodiment, a pair of vertical channel transistors may be provided to share one of the bit lines BL.

[0058] In an embodiment, the channel patterns CP may be formed of or include at least one of oxide semiconductor materials (e.g., $\text{In}_x\text{Ga}_y\text{Zn}_z\text{O}$, $\text{In}_x\text{Ga}_y\text{Si}_z\text{O}$, $\text{In}_x\text{Sn}_y\text{Zn}_z\text{O}$, $\text{In}_x\text{Zn}_y\text{O}$, Zn_xO , $\text{Zn}_x\text{Sn}_y\text{O}$, $\text{Zn}_x\text{O}_y\text{N}$, $\text{Zr}_x\text{Zn}_y\text{Sn}_z\text{O}$, Sn_xO , $\text{Hf}_x\text{In}_y\text{Zn}_z\text{O}$, $\text{Ga}_x\text{Zn}_y\text{Sn}_z\text{O}$, $\text{Al}_x\text{Zn}_y\text{Sn}_z\text{O}$, $\text{Yb}_x\text{Ga}_y\text{Zn}_z\text{O}$, $\text{In}_x\text{Ga}_y\text{O}$, or combinations thereof). As an example, the channel patterns CP may be formed of or include indium gallium zinc oxide (IGZO). The channel patterns CP may include a single or

multiple layer made of the oxide semiconductor material. The channel patterns CP may be formed of or include an amorphous, single-crystalline, or poly-crystalline oxide semiconductor material. In an embodiment, the channel patterns CP may have a band gap energy that is greater than that of silicon. For example, the channel patterns CP may have a band gap energy of about 1.5 eV to 5.6 eV. In an embodiment, when the channel patterns CP have a band gap energy of about 2.0 eV to 4.0 eV, they may have an optimized channel property. In an embodiment, the channel patterns CP may have polycrystalline or amorphous structure. In an embodiment, the channel patterns CP may be formed of or include a two-dimensional semiconductor material (e.g., graphene, carbon nanotube, or combinations thereof).

[0059] Referring to FIGS. 3, 4A, and 4B, the first and second word lines WL1 and WL2 may be provided on the channel patterns CP to cross the bit lines BL and to extend in the second direction D2. The first and second word lines WL1 and WL2 may be alternately arranged in the first direction D1. A pair of the first and second word lines WL1 and WL2 may be provided on the horizontal channel portion HCP of each channel pattern CP to be symmetric with respect to each other.

[0060] The first and second word lines WL1 and WL2 may be formed of or include at least one of, e.g., doped polysilicon, metallic materials, conductive metal nitrides, conductive metal silicides, conductive metal oxides, or combinations thereof. The first and second word lines WL1 and WL2 may be formed of at least one of, e.g., doped polysilicon, Al, Cu, Ti, Ta, Ru, W, Mo, Pt, Ni, Co, TiN, TaN, WN, NbN, TiAl, TiAlN, TiSi, TiSiN, TaSi, TaSiN, RuTiN, NiSi, CoSi, IrOx, RuOx, or combinations thereof. The first and second word lines WL1 and WL2 may have a single- or multi-layered structure that is formed of at least one of the afore-described materials. In an embodiment, the first and second word lines WL1 and WL2 may be formed of or include a two-dimensional semiconductor material (e.g., graphene, carbon nanotube, or combinations thereof).

[0061] In more detail, referring to FIG. 5A, the first word line WL1 may include a first horizontal portion HP1, which is disposed on the horizontal channel portion HCP of the channel pattern CP, and a first vertical portion VP1, which is vertically extended from the first horizontal

portion HP1, e.g., the first horizontal portion HP1 with the first vertical portion VP1 may have an L-shaped cross-section. The first vertical portion VP1 of the first word line WL1 may be adjacent to the inner side surface of the first vertical channel portion VCP1 of the channel pattern CP.

[0062] The second word line WL2 may include a second horizontal portion HP2, which is disposed on the horizontal channel portion HCP of the channel pattern CP, and a second vertical portion VP2, which is vertically extended from the second horizontal portion HP2. The second vertical portion VP2 of the second word line WL2 may be adjacent to the inner side surface of the second vertical channel portion VCP2 of the channel pattern CP.

[0063] The first horizontal portion HP1 of the first word line WL1 may have a first thickness on a top surface of the horizontal channel portion HCP, and the first vertical portion VP1 of the first word line WL1 may have a second thickness, e.g., a width along the first direction D1, which is substantially equal to the first thickness, on a side surface of the first vertical channel portion VCP1. The second word line WL2 may also be provided to have the same feature as the first word line WL1.

[0064] The first and second horizontal portions HP1 and HP2 of the first and second word lines WL1 and WL2 may have a first horizontal width HW1 in the first direction D1, e.g., each of the first and second horizontal portions HP1 and HP2 may have the first horizontal width HW1 in the first direction D1. Here, the first horizontal width HW1 may be smaller than half the first length L1 of the channel pattern CP in the first direction D1.

[0065] A first spacer SP1 may be disposed on the first horizontal portion HP1 of the first word line WL1, and a second spacer SP2 may be disposed on the second horizontal portion HP2 of the second word line WL2. The first spacer SP1 may be aligned with a side surface of the first horizontal portion HP1 of the first word line WL1, e.g., surfaces of the first spacer SP1 and first horizontal portion HP1 facing away from the first vertical portion VP1 may be coplanar, and the second spacer SP2 may be aligned with a side surface of the second horizontal portion HP2 of the second word line WL2 e.g., surfaces of the second spacer SP2 and second horizontal portion HP2 facing away from the second vertical portion VP2 may be coplanar.

[0066] A first capping pattern 151 and a gap-fill insulating pattern 153 may be disposed between a pair of the first and second spacers SP1 and SP2. The first capping pattern 151 may be disposed between side surfaces of the first and second spacers SP1 and SP2 and the gap-fill insulating pattern 153, and between a top surface of the horizontal channel portion HCP of the channel pattern CP and the gap-fill insulating pattern 153. The first capping pattern 151 may have a substantially uniform thickness and may be formed of an insulating material different from the gap-fill insulating pattern 153. The first capping pattern 151 and the gap-fill insulating pattern 153 may be extended in the second direction D2.

[0067] A second capping pattern 155 may be provided on top surfaces of the first and second vertical portions VP1 and VP2 of the first and second word lines WL1 and WL2. The second capping pattern 155 may cover a top surface of the first capping pattern 151 and a top surface of the gap-fill insulating pattern 153. The second capping pattern 155 may be extended in the second direction D2. In an embodiment, a top surface of the second capping pattern 155 may be substantially coplanar with a top surface of the mold insulating pattern 125. The second capping pattern 155 may be formed of an insulating material that is different from the gap-fill insulating pattern 153.

[0068] Referring to FIG. 5A, a first gate insulating pattern Gox1 may be disposed between the first word line WL1 and the channel pattern CP, and a second gate insulating pattern Gox2 may be disposed between the second word line WL2 and the channel pattern CP.

[0069] The first and second gate insulating patterns Gox1 and Gox2 may be extended in the second direction D2 to be parallel to the first and second word lines WL1 and WL2. The first and second gate insulating patterns Gox1 and Gox2 may cover surfaces of the channel patterns CP with a uniform thickness. As shown in FIG. 4B, between adjacent ones of the channel patterns CP in the second direction D2, the gate insulating pattern Gox may be in direct contact with a top surface of the first insulating pattern 121 and a side surface of the mold insulating pattern 125.

[0070] Each of the first and second gate insulating patterns Gox1 and Gox2 may have substantially a 'L'-shaped section, like the first and second word lines WL1 and WL2. In other

words, each of the first and second gate insulating patterns Gox1 and Gox2 may include a horizontal portion covering the horizontal channel portion HCP and a vertical portion covering the first and second vertical channel portions VCP1 and VCP2, similar to the first and second word lines WL1 and WL2. In addition, the first gate insulating pattern Gox1 and the second gate insulating pattern Gox2 may be disposed to have mirror symmetry with respect to each other in the first direction D1. A side surface of the first gate insulating pattern Gox1 may be aligned with the first spacer SP1, and a side surface of the second gate insulating pattern Gox2 may be aligned with the second spacer SP2.

[0071] The first and second gate insulating patterns Gox1 and Gox2 may be formed of at least one of, e.g., silicon oxide, silicon oxynitride, high-k dielectric materials whose dielectric constants are higher than the silicon oxide, or combinations thereof. The high-k dielectric materials may include at least one of, e.g., metal oxides or metal oxynitrides. For example, the high-k dielectric material for the gate insulating layer may include HfO₂, HfSiO, HfSiON, HfTaO, HfTiO, HfZrO, ZrO₂, Al₂O₃, or combinations thereof.

[0072] Meanwhile, in the embodiment shown in FIG. 5B, the gate insulating pattern Gox may be provided to cover an inner surface of the channel pattern CP with a uniform thickness. The gate insulating pattern Gox may be disposed in common between the channel pattern CP and the first and second word lines WL1 and WL2. A portion of the gate insulating pattern Gox may be disposed between the first and second word lines WL1 and WL2. In this case, the portion of the gate insulating pattern Gox may be in contact with the first capping pattern 151.

[0073] In the embodiment shown in FIG. 5C, the first and second channel patterns CP1 and CP2 may be spaced apart from each other in the first direction D1 on the bit line BL, and may be disposed to have mirror symmetry with respect to each other. The first channel pattern CP1 may include a first horizontal channel portion HCP1, which is in contact with the bit line BL, and the first vertical channel portion VCP1, which is vertically extended from the first horizontal channel portion HCP1 and is adjacent to the first vertical portion VP1 of the first word line WL1. The second channel pattern CP2 may include a second horizontal channel portion HCP2, which is in contact with the bit line BL, and the second vertical channel portion VCP2, which is

vertically extended from the second horizontal channel portion HCP2 and is adjacent to the second vertical portion VP2 of the second word line WL2.

[0074] The side surface of the first horizontal channel portion HCP1 of the first channel pattern CP1 and the side surface of the first gate insulating pattern Gox1 may be aligned, e.g., coplanar, with the side surface of the first horizontal portion HP1 of the first word line WL1. Similarly, the side surface of the second horizontal channel portion HCP2 of the second channel pattern CP2 and the side surface of the second gate insulating pattern Gox2 may be aligned, e.g., coplanar, with the side surface of the second horizontal portion HP2 of the second word line WL2.

[0075] When measured in the first direction D1, the first and second horizontal portions HP1 and HP2 of the first and second word lines WL1 and WL2 may have the first horizontal width HW1, and the first and second horizontal channel portions HCP1 and HCP2 of the first and second channel patterns CP1 and CP2 may have a second horizontal width HW2 that is larger than the first horizontal width HW1. In the case where the first and second channel patterns CP1 and CP2 are spaced apart from each other on the bit line BL, the first capping pattern 151 may be in contact with the top surface of the bit line BL, between the first and second channel patterns CP1 and CP2.

[0076] In the embodiment shown in FIG. 5D, the first and second spacers SP1 and SP2 of FIG. 5A may be omitted, and the first capping pattern 151 may cover the surfaces of the first and second word lines WL1 and WL2 with a uniform thickness. For example, as illustrated in FIG. 5D, the first capping pattern 151 may be conformal on the gap-fill insulating pattern 153, and the first capping pattern 151 with the gap-fill insulating pattern 153 may fill an entire space between facing surfaces of the first and second word lines WL1 and WL2 with a uniform thickness

[0077] In the embodiment shown in FIG. 5E, the first and second spacers SP1 and SP2 of FIG. 5C may be omitted, and the first capping pattern 151 may cover the surfaces of the first and second word lines WL1 and WL2, the side surfaces of the first and second channel patterns CP1 and CP2, and a portion of the bit line BL with a uniform thickness.

[0078] Referring back to FIGS. 3, 4A, 4B, and 5A, landing pads LP may be disposed on the first and second vertical channel portions VCP1 and VCP2 of the channel pattern CP. The landing pads LP may be in direct contact with the first and second vertical channel portions VCP1 and VCP2. The landing pad LP may include a portion that is interposed between the side surface of the mold insulating pattern 125 and the side surface of the gate insulating pattern Gox1 or Gox2, as shown in FIG. 5A. The landing pads LP may have various shapes, e.g., circular, elliptical, rectangular, square, diamond, hexagonal shapes, when viewed in a plan view. The landing pads LP may be formed of or include at least one of, e.g., doped polysilicon, Al, Cu, Ti, Ta, Ru, W, Mo, Pt, Ni, Co, TiN, TaN, WN, NbN, TiAl, TiAlN, TiSi, TiSiN, TaSi, TaSiN, RuTiN, NiSi, CoSi, IrOx, RuOx, or combinations thereof.

[0079] A third insulating pattern 165 may be provided to fill a region between the landing pads LP. In other words, the landing pads LP may be separated from each other by the third insulating pattern 165.

[0080] In an embodiment, the data storage patterns DSP may be disposed on the landing pads LP, respectively. The data storage patterns DSP may be electrically connected to the first and second vertical channel portions VCP1 and VCP2 of the channel patterns CP, respectively, through the landing pads LP. The data storage patterns DSP may be arranged in a matrix shape (e.g., in the first and second directions D1 and D2), as shown in FIG. 3.

[0081] In an embodiment, the data storage pattern DSP may be a capacitor and may include bottom and top electrodes and a capacitor dielectric layer therebetween. In this case, the bottom electrode may be in contact with the landing pad LP and may have various shapes (e.g., circular, elliptical, rectangular, square, lozenge, and hexagonal shapes), when viewed in a plan view.

[0082] Alternatively, the data storage patterns DSP may be a variable resistance pattern whose resistance can be switched to one of at least two states by an electric pulse applied to a memory element. For example, the data storage patterns DSP may be formed of or include at least one of, e.g., phase-change materials whose crystal state can be changed depending on an amount of a current applied thereto, perovskite compounds, transition metal oxides, magnetic materials, ferromagnetic materials, or antiferromagnetic materials.

[0083] Furthermore, upper conductive patterns UCP may be disposed on the mold insulating pattern 125 of the peripheral circuit region PCR and may be formed of or include the same conductive material as the landing pads LP. The upper conductive patterns UCP may be connected to the lower conductive patterns LCP through lower conductive vias LVP.

[0084] An etch stop layer 171 may cover the top surfaces of the landing pads LP and the upper conductive patterns UCP, and a fourth insulating layer 173 may be provided on the etch stop layer 171. The fourth insulating layer 173 may be provided on the cell array region CAR to cover the data storage patterns DSP.

[0085] On the peripheral circuit region PCR, connection lines CL may be provided on the fourth insulating layer 173. The connection lines CL may be connected to the upper conductive patterns UCP through upper conductive vias UVP.

[0086] Hereinafter, semiconductor devices according to some embodiments will be described. In the following description, a previously described element may be identified by the same reference number without repeating an overlapping description thereof, for the sake of brevity.

[0087] FIGS. 6A and 6B are sectional views illustrating cross-sections taken along the lines A-A', B-B', C-C', and D-D' of FIG. 3.

[0088] In the embodiment shown in FIGS. 6A and 6B, the semiconductor memory device may include word-line shielding structures WS or air gaps, each of which is provided between a corresponding pair of the first and second word lines WL1 and WL2.

[0089] The word-line shielding structures WS may be extended in the second direction D2 to be parallel to the first and second word lines WL1 and WL2. The word-line shielding structures WS may be formed by forming an insulating layer to define gap regions, when the gap-fill insulating patterns 153 are formed after the formation of the first and second word lines WL1 and WL2, and filling the gap region of the insulating layer with a conductive material. The word-line shielding structures WS may be locally formed in the gap-fill insulating patterns 153. Alternatively, the air gaps may be formed in the gap-fill insulating pattern 153 by depositing an insulating layer using a deposition method having a poor step coverage property when the gap-fill insulating patterns 153 are formed.

[0090] FIG. 7 is a plan view illustrating a semiconductor memory device according to an embodiment.

[0091] In the embodiment shown in FIG. 7, the landing pads LP and the data storage patterns DSP may be arranged in a zigzag or honeycomb shape, when viewed in a plan view. The data storage patterns DSP may be fully or partially overlapped with the landing pads LP. Each of the data storage patterns DSP may be in contact with the entire or partial region of the top surface of a corresponding one of the landing pads LP.

[0092] FIG. 8 is a perspective view schematically illustrating a semiconductor memory device according to an embodiment.

[0093] Referring to FIG. 8, the semiconductor memory device may include the cell array structure CS on the semiconductor substrate 100 and the peripheral circuit structure PS on the cell array structure CS. In an embodiment, the cell array structure CS may be provided between the semiconductor substrate 100 and the peripheral circuit structure PS, in the third direction D3 perpendicular to the top surface of the semiconductor substrate 100.

[0094] The cell array structure CS may include the bit lines BL, the word lines WL, and memory cells therebetween, as described above. Each of the memory cells may include a vertical channel transistor, which is used as the selection element TR (e.g., see FIG. 1), and a capacitor, which is used as the data storage element DS (e.g., see FIG. 1). The peripheral circuit structure PS may include core and peripheral circuits, which are formed on a semiconductor layer provided on an insulating layer.

[0095] FIGS. 9A and 9B are sectional views illustrating cross-sections taken along the lines A-A', B-B', C-C', D-D', and E-E' of FIG. 3 (e.g., to reflect the structure of FIG. 8).

[0096] Referring to FIGS. 3, 9A, and 9B, the cell array structure CS may include the bit lines BL, the first and second word lines WL1 and WL2, the channel patterns CP, and the data storage patterns DSP, which are disposed on the lower insulating pattern 111 covering the semiconductor substrate 100.

[0097] The bit lines BL may be disposed on the lower insulating pattern 111 covering the semiconductor substrate 100. The bit lines BL may be extended in the first direction D1 and

may be spaced apart from each other in the second direction D2. The shielding structures SS may be provided between the bit lines BL.

[0098] The first and second word lines WL1 and WL2, the channel patterns CP, and the data storage patterns DSP may be configured to have substantially the same technical features as those in the embodiments described with reference to FIGS. 3, 4A, 4B, and 5A to 5E.

[0099] A semiconductor layer 180 may be disposed on the fourth insulating layer 173 of the cell array structure CS. The semiconductor layer 180 may be a single- or poly-crystalline silicon layer.

[00100] The core and peripheral circuits SA and PC of the peripheral circuit structure PS may be provided on the semiconductor layer 180. The peripheral circuit insulating layer ILD, the peripheral contact plugs PCT, and the peripheral circuit lines PCL may be provided on the semiconductor layer 180, and here, the peripheral circuit insulating layer ILD may be provided to cover the core and peripheral circuits SA and PC. The peripheral circuit lines PCL may be coupled to the connection lines CL through the peripheral contact plugs PCT, which are formed to penetrate the peripheral circuit insulating layer ILD and the semiconductor layer 180. The peripheral contact plug PCT penetrating the semiconductor layer 180 may be surrounded by an insulating material. An uppermost insulating layer 190 may be provided to cover top surfaces of the peripheral circuit lines PCL.

[00101] FIG. 10 is a perspective view schematically illustrating a semiconductor memory device according to an embodiment.

[00102] Referring to FIG. 10, the semiconductor memory device may have a chip-to-chip (C2C) structure. In the C2C structure, an upper chip including the cell array structure CS may be fabricated on the semiconductor substrate 100, e.g., a wafer, a lower chip including the peripheral circuit structure PS may be fabricated on a second semiconductor substrate 200, e.g., a wafer, which is different from the first semiconductor substrate 100, and then, the upper and lower chips may be connected to each other through a bonding process. Here, the bonding process may be performed to electrically connect a bonding metal pad, which is formed in the uppermost metal layer of the upper chip, to a bonding metal pad, which is formed in the

uppermost metal layer of the lower chip. For example, in the case where the bonding metal pad is formed of copper (Cu), the bonding process may be performed in a Cu-to-Cu bonding manner, but in an embodiment, the bonding metal pad may be formed of or include aluminum (Al) or tungsten (W).

[00103] The cell array structure CS may be provided on the first semiconductor substrate 100, and lower metal pads LMP may be provided in the uppermost layer of the cell array structure CS (e.g., relative to the first semiconductor substrate 100). The lower metal pads LMP may be electrically connected to the memory cell array 1 (e.g., see FIG. 1).

[00104] The peripheral circuit structure PS may be provided on the second semiconductor substrate 200, and upper metal pads UMP may be provided in the uppermost layer of the peripheral circuit structure PS (e.g., relative to the second semiconductor substrate 200). The upper metal pads UMP may be electrically connected to the core and peripheral circuits 2, 3, 4, and 5 (e.g., see FIG. 1). The upper metal pads UMP may be directly bonded to the lower metal pads LMP of the cell array structure CS and may be in direct contact with the lower metal pads LMP. That is, as illustrated in FIG. 10, the uppermost layers of the cell array structure CS and the peripheral circuit structure PS may be connected to each other via the upper metal pads UMP and the lower metal pads LMP, e.g., the combined upper metal pads UMP and lower metal pads LMP may be between the first and second semiconductor substrate 100 and 200.

[00105] FIGS. 11A and 11B are sectional views illustrating cross-sections taken along the lines A-A', B-B', C-C', and D-D' of FIG. 3 (e.g., to reflect the structure of FIG. 10).

[00106] Referring to FIGS. 3, 11A, and 11B, the semiconductor memory device may include the cell array structure CS, which includes the lower metal pads LMP provided at its uppermost level, and the peripheral circuit structure PS, which includes the upper metal pads UMP provided at its uppermost level. Here, the lower metal pads LMP of the cell array structure CS and the upper metal pads UMP of the peripheral circuit structure PS may be electrically and physically connected to each other in a bonding manner. The lower and upper metal pads LMP and UMP may be formed of or include at least one metallic material (e.g., copper (Cu)). In other words, the lower metal pads LMP may be in direct contact with the upper metal pads UMP.

[00107] In detail, the cell array structure CS may include the bit lines BL, the first and second word lines WL1 and WL2, the channel patterns CP, the data storage patterns DSP, and the lower metal pads LMP, which are disposed on the lower insulating pattern 111 covering the semiconductor substrate 100. The bit lines BL, the first and second word lines WL1 and WL2, the channel patterns CP, and the data storage patterns DSP may be configured to have substantially the same technical features as those in the embodiments described with reference to FIGS. 3, 4A, 4B, and 5A to 5E.

[00108] Cell metal structures CCL may be provided on the fourth insulating layer 173 covering the data storage patterns DSP, and in this case, the cell metal structures CCL may be electrically connected to the bit lines BL and the first and second word lines WL1 and WL2. The lower metal pads LMP may be disposed in the uppermost layer (e.g., the uppermost insulating layer 190) of the cell array structure CS.

[00109] The peripheral circuit structure PS may include the core and peripheral circuits SA, which are integrated on the second semiconductor substrate 200, the peripheral circuit contact plugs PCT and the peripheral circuit lines PCL, which are electrically connected to the core and peripheral circuits SA, and the upper metal pads UMP, which are electrically connected to the peripheral circuit lines PCL. The upper metal pads UMP may be disposed in the uppermost layer (e.g., a peripheral insulating layer 220) of the peripheral circuit structure PS.

[00110] The lower and upper metal pads LMP and UMP may have substantially the same size and arrangement. The lower and upper metal pads LMP and UMP may be formed of or include at least one of, e.g., copper (Cu), aluminum (Al), nickel (Ni), cobalt (Co), tungsten (W), titanium (Ti), tin (Sn), or alloys thereof.

[00111] FIGS. 12A to 19A are plan views illustrating stages in a method of fabricating a semiconductor memory device, according to an embodiment. FIGS. 12B to 19B and 20A to 23A are cross-sections along lines A-A' and B-B' of FIGS. 12A to 19A, respectively, and FIGS. 12C to 19C and 20B to 23B are cross-sections along lines C-C', D-D', and E-E of FIGS. 12A to 19A, respectively.

[00112] Referring to FIGS. 12A, 12B, and 12C, the peripheral circuit structure PS including the core and peripheral circuits SA and PC may be formed on the semiconductor substrate 100.

[00113] The semiconductor substrate 100 may include the cell array region CAR and the peripheral circuit region PCR. The core circuit SA including the sense amplifier 3 (FIG. 1) may be formed on the cell array region CAR of the semiconductor substrate 100. The peripheral circuit PC, e.g. the word line driver and the control logic 5 (FIG. 1), may be formed on the peripheral circuit region PCR of the semiconductor substrate 100. The core and peripheral circuits SA and PC may include NMOS and PMOS transistors, which are integrated on the semiconductor substrate 100.

[00114] The peripheral circuit insulating layer ILD may be formed on the top surface of the semiconductor substrate 100. The peripheral circuit insulating layer ILD may be formed on the semiconductor substrate 100 to cover the core and peripheral circuits SA and PC and the peripheral circuit lines PCL. The peripheral circuit insulating layer ILD may include a plurality of vertically-stacked insulating layers. In an embodiment, the peripheral circuit insulating layer ILD may include, e.g., a silicon oxide layer, a silicon nitride layer, a silicon oxynitride layer, and/or a low-k dielectric layer.

[00115] The peripheral contact plugs PCT and the peripheral circuit lines PCL may be formed in the peripheral circuit insulating layer ILD. The peripheral contact plugs PCT and the peripheral circuit lines PCL may be electrically connected to the core and peripheral circuits SA and PC.

[00116] The bit lines BL may be formed in the cell array region CAR and on the peripheral circuit insulating layer ILD. The bit lines BL may be extended in the first direction D1 and may be spaced apart from each other in the second direction D2. The formation of the bit lines BL may include forming a lower insulating layer on the semiconductor substrate 100 to cover the peripheral circuit insulating layer ILD, forming the lower contact plugs LCT to penetrate the lower insulating layer and to be connected to the peripheral circuit lines PCL, depositing a lower conductive layer on the lower insulating layer, and patterning the lower conductive layer and the lower insulating layer to form the bit lines BL on the cell array region CAR.

[00117] During an etching process for forming the bit lines BL, the lower insulating layer may be etched to form the lower insulating pattern 111 and to expose the peripheral circuit insulating layer ILD. During the formation of the bit lines BL, the lower conductive layer and the lower insulating layer may be patterned to form the lower conductive patterns LCP on the peripheral circuit region PCR. The lower conductive patterns LCP may be connected to the peripheral circuit PC through the lower contact plugs LCT and the peripheral circuit lines PCL.

[00118] Referring to FIGS. 13A, 13B, and 13C, after the formation of the bit lines BL, a first insulating layer 120 may be formed to define gap regions between the bit lines BL. The first insulating layer 120 may be deposited on the semiconductor substrate 100 to have a substantially uniform thickness.

[00119] A deposition thickness of the first insulating layer 120 may be smaller than half a distance between adjacent ones of the bit lines BL. In the case where the first insulating layer 120 is deposited in this manner, the gap region between the bit lines BL may be defined by the first insulating layer 120. The gap region may be extended in the first direction D1 to be parallel to the bit lines BL.

[00120] Meanwhile, before the formation of the first insulating layer 120, an insulating material 115 may be formed on the peripheral circuit region PCR to fill a region between the lower conductive patterns LCP.

[00121] After the formation of the first insulating layer 120, the shielding structures SS may be formed on the first insulating layer 120 to fill the gap regions. The shielding structures SS may be formed between the bit lines BL.

[00122] The formation of the shielding structures SS may include forming a shielding layer on the first insulating layer 120 to fill the gap region and recessing a top surface of the shielding layer. The shielding structures SS may have top surfaces that are located at a level lower than the top surfaces of the bit lines BL.

[00123] The shielding layer may be deposited on the first insulating layer 120 using a chemical vapor deposition (CVD) process, and owing to the step coverage property of the CVD process, a discontinuous interface (e.g., a seam) may be formed. Furthermore, if the CVD process has a

poor step coverage property, an over-hang issue may occur, and in this case, a void or air gap may be formed in the gap region.

[00124] For example, the shielding structures SS may be formed of or include at least one metallic material (e.g., tungsten (W), titanium (Ti), nickel (Ni), or cobalt (Co)). In another example, the shielding structures SS may be formed of or include a conductive two-dimensional (2D) material (e.g., graphene).

[00125] In an embodiment, the process of forming the shielding structures SS may be omitted, and spaces between the bit lines BL may be filled with the first insulating layer 120. Alternatively, the first insulating layer 120 may include a plurality of air gaps which are defined between the bit lines BL.

[00126] Referring to FIGS. 14A, 14B, and 14C, after the formation of the shielding structures SS, a capping insulating layer may be formed on the shielding structures SS, and a planarization process may be performed on the capping insulating layer and the first insulating layer 120 to expose the top surfaces of the bit lines BL. Accordingly, the first insulating patterns 121 may be formed between the bit lines BL and the shielding structures SS.

[00127] Next, the mold insulating pattern 125 may be formed on the first insulating patterns 121 and the bit lines BL. The mold insulating pattern 125 may define trenches T, which are extended in the second direction D2 and are spaced apart from each other in the first direction D1. The trenches T may be formed to cross the bit lines BL and to expose portions of the bit lines BL.

[00128] In an embodiment, distances between the channel patterns CP may vary depending on a width of the mold insulating pattern 125 (e.g., a distance between the trenches T). In addition, distances between the first and second word lines WL1 and WL2 may vary depending on widths of the trenches T.

[00129] The mold insulating pattern 125 may be formed of or include an insulating material having an etch selectivity with respect to the first insulating pattern 121. For example, the mold insulating pattern 125 may be formed of or include at least one of silicon oxide, silicon nitride, silicon oxynitride, and/or low-k dielectric materials.

[00130] Referring to FIGS. 15A, 15B, and 15C, a channel layer 131 may be formed to conformally cover the mold insulating pattern 125 having the trenches T. The channel layer 131 may be in contact with the bit lines BL, in the trenches T, and may cover the top and side surfaces of the mold insulating pattern 125.

[00131] The channel layer 131 may be formed using at least one of, e.g., physical vapor deposition (PVD), thermal chemical vapor deposition (thermal CVD), low pressure chemical vapor deposition (LP-CVD), plasma-enhanced chemical vapor deposition (PE-CVD), or atomic layer deposition (ALD) technologies. The channel layer 131 may cover bottom and inner side surfaces of the trenches T with a substantially uniform thickness. A thickness of the channel layer 131 may be smaller than half the width of the trench. The channel layer 131 may be deposited to have a thickness of several nanometers to several tens of nanometers (e.g., of 1 nm to 30 nm) and in particular to have a thickness of 1 nm to 10 nm. The channel layer 131 may be formed of or include at least one of, e.g., semiconductor materials, oxide semiconductor materials, or two-dimensional semiconductor materials. The channel layer 131 may be formed of or include at least one of, e.g., silicon, germanium, silicon germanium, or indium gallium zinc oxide (IGZO).

[00132] A first sacrificial layer 133 may be formed on the channel layer 131 to fill the trenches. The first sacrificial layer 133 may have a substantially flat top surface. The first sacrificial layer 133 may be formed of or include an insulating material having an etch selectivity with respect to the mold insulating pattern 125. For example, the first sacrificial layer 133 may be one of insulating layers, which are formed by a spin-on-glass (SOG) technique, or a silicon oxide layer.

[00133] Next, referring to FIGS. 16A, 16B, and 16C, a mask pattern MP may be formed on the first sacrificial layer 133.

[00134] The mask pattern MP may be disposed to cross the mold insulating patterns 125 and may have openings which are formed to have a long axis in the first direction D1. The openings of the mask pattern MP may be spaced apart from each other in the second direction D2. The openings of the mask pattern MP may be located between the bit lines BL, when viewed in a plan view.

[00135] Thereafter, the first sacrificial layer 133 and the channel layer 131 may be sequentially etched using the mask pattern MP as an etch mask, and as a result, openings OP may be formed between the bit lines BL to expose the first insulating pattern 121. The openings OP may be overlapped with the shielding structures SS, when viewed in a plan view.

[00136] As a result of the formation of the openings OP, preliminary channel patterns 132 may be formed in each of the trenches T. The preliminary channel patterns 132 may be spaced apart from each other in the second direction D2. After the formation of the preliminary channel patterns 132, an ashing process may be performed to remove the mask pattern MP.

[00137] Referring to FIGS. 17A, 17B, and 17C, after the formation of the preliminary channel patterns 132, a second sacrificial layer may be formed to fill the openings. The second sacrificial layer may be formed of the same material as the first sacrificial layer 133.

[00138] After the formation of the second sacrificial layer, a planarization process may be performed on the first sacrificial layer 133, the second sacrificial layer, and the preliminary channel patterns 132 to expose the top surface of the mold insulating pattern 125. As a result, the channel patterns CP, first sacrificial patterns 135, and second sacrificial patterns 137 may be formed.

[00139] The channel patterns CP may be formed to be spaced apart from each other in the first and second directions D1 and D2. Each of the channel patterns CP may include a horizontal channel portion, which is in contact with the bit line BL, and a pair of vertical channel portions, which are extended from the horizontal channel portion to be in contact with the side surfaces of the trench T. The channel patterns CP may be spaced apart from each other in the first direction D1 by the mold insulating pattern 125 and may be spaced apart from each other in the second direction D2 by the second sacrificial patterns 137.

[00140] The first sacrificial patterns 135 may be formed on the channel patterns CP, respectively, and the second sacrificial patterns 137 may be formed between the channel patterns CP, which are adjacent to each other in the second direction D2, and between the first sacrificial patterns 135, which are adjacent to each other in the second direction D2.

[00141] After the formation of the channel patterns CP, the first and second sacrificial patterns 135 and 137 may be removed using an etch recipe, which is chosen to have an etch selectivity with respect to the mold insulating pattern 125 and the channel patterns CP. As a result, the surfaces of the channel patterns CP may be exposed to the outside.

[00142] Referring to FIGS. 18A, 18B, and 18C, a gate insulating layer 141, a gate conductive layer 143, and a spacer layer 145 may be sequentially deposited to conformally cover the channel patterns CP. In an embodiment, channel lengths of the vertical channel transistors may be determined by a deposition thickness of the spacer layer 145.

[00143] The gate insulating layer 141, the gate conductive layer 143, and the spacer layer 145 may be formed using at least one of, e.g., physical vapor deposition (PVD), thermal chemical vapor deposition (thermal CVD), low-pressure chemical vapor deposition (LP-CVD), plasma-enhanced chemical vapor deposition (PE-CVD), and atomic layer deposition (ALD) technologies.

[00144] The gate insulating layer 141, the gate conductive layer 143, and the spacer layer 145 may cover the horizontal and vertical channel portions of the channel patterns CP with a substantially uniform thickness. A sum of thicknesses of the gate insulating layer 141, the gate conductive layer 143, and the spacer layer 145 may be smaller than half the width of the trench T. Accordingly, the spacer layer 145 may be deposited on the gate conductive layer 143 to define a gap region in the trench.

[00145] The spacer layer 145 may be formed of or include an insulating material. For example, the spacer layer 145 may be formed of or include at least one of silicon nitride (SiN), silicon oxynitride (SiON), silicon carbide (SiC), silicon carbon nitride (SiCN), and combinations thereof.

[00146] Referring to FIGS. 19A, 19B, and 19C, an anisotropic etching process may be performed on the spacer layer 145 to form a pair of spacers SP1 and SP2, which are spaced apart from each other, on the gate conductive layer.

[00147] Next, an anisotropic etching process using the spacers SP1 and SP2 as an etch mask may be performed on the gate conductive layer 143. As a result, a pair of the first and second

word lines WL1 and WL2 may be formed to be spaced apart from each other in each trench T. During the anisotropic etching process on the gate conductive layer 143, the first and second word lines WL1 and WL2 may have top surfaces that are lower than a top surface of the channel pattern CP. In an embodiment, an etching process of recessing the top surfaces of the first and second word lines WL1 and WL2 may be additionally performed.

[00148] During the anisotropic etching process on the gate conductive layer 143, the gate insulating layer 141 may be etched to expose the horizontal channel portion of the channel pattern CP. As a result, the first and second gate insulating patterns Gox1 and Gox2 may be formed.

[00149] As another example, during the anisotropic etching process on the gate conductive layer 143, the horizontal channel portion of the channel pattern CP may be etched to expose portions of the bit lines BL in each trench. In this case, as shown in FIG. 5C, a pair of the first and second channel patterns CP1 and CP2 may be formed to be spaced apart from each other in each trench, and a pair of the first and second gate insulating patterns Gox1 and Gox2 may be formed to be spaced apart from each other in each trench.

[00150] Referring to FIGS. 20A and 20B, a first capping layer 150 may be conformally formed on the top surface of the semiconductor substrate 100. The first capping layer 150 may be formed of or include at least one of, e.g., silicon nitride (SiN), silicon oxynitride (SiON), silicon carbide (SiC), silicon carbon nitride layer (SiCN), and combinations thereof.

[00151] The first capping layer 150 may be formed to cover the channel patterns CP between a pair of word lines WL1 and WL2. As another example, the spacers SP1 and SP2 may be removed, before the formation of the first capping layer 150. In this case, the first capping layer 150 may be formed to directly cover the first and second word lines WL1 and WL2.

[00152] Next, a second insulating layer 152 and a second capping layer 154 may be sequentially formed to fill the trench, in which the first capping layer 150 is formed. The second insulating layer 152 may be formed of an insulating material that is different from the first capping layer 150. The second capping layer 154 may be formed of the same material as the first capping layer 150, and the second capping layer 154 may be omitted.

[00153] Next, referring to FIGS. 21A and 21B, a planarization process may be performed on the first capping layer 150, the second insulating layer 152, and the second capping layer 154 to expose the top surface of the mold insulating pattern 125. Accordingly, the first capping pattern 151, the gap-fill insulating pattern 153, and the second capping pattern 155 may be formed. The second capping pattern 155 may be formed to have a top surface that is coplanar with the top surface of the mold insulating pattern 125.

[00154] Next, an etch stop layer 160 may be formed on the top surface of the semiconductor substrate 100. The etch stop layer 160 may be formed of or include an insulating material having an etch selectivity with respect to the mold insulating pattern 125. For example, the etch stop layer 160 may be formed of or include at least one of, e.g., silicon nitride (SiN), silicon oxynitride (SiON), silicon carbide (SiC), silicon carbon nitride (SiCN), or combinations thereof.

[00155] After the formation of the etch stop layer 160, the lower conductive vias LVP may be formed on the peripheral circuit region PCR to penetrate the mold insulating pattern 125 and to be coupled to the lower conductive patterns LCP.

[00156] After the formation of the lower conductive vias LVP, as shown in FIGS. 22A and 22B, a mask pattern may be formed on the etch stop layer 160 to expose the cell array region CAR. Then, the etch stop layer 160 may be etched using the mask pattern as an etch mask to expose the top surface of the mold insulating pattern 125 and the top surfaces of the channel patterns CP on the cell array region CAR.

[00157] Next, an etching process may be performed on portions of the channel patterns CP to form recess regions between the mold insulating pattern 125 and the first and second gate insulating patterns Gox1 and Gox2. Accordingly, the top surfaces of the channel patterns CP may be located at a level lower than the top surface of the mold insulating pattern 125. In addition, the top surfaces of the channel patterns CP may be located at a level different from the top surfaces of the first and second word lines WL1 and WL2.

[00158] Next, a conductive layer 170 may be formed on the semiconductor substrate 100 to fill the recess regions. The conductive layer 170 may be formed of or include at least one of, e.g.,

doped polysilicon, Al, Cu, Ti, Ta, Ru, W, Mo, Pt, Ni, Co, TiN, TaN, WN, NbN, TiAl, TiAlN, TiSi, TiSiN, TaSi, TaSiN, RuTiN, NiSi, CoSi, IrOx, RuOx, or combinations thereof.

[00159] Referring to FIGS. 23A and 23B, the conductive layer 170 may be patterned to form the landing pads LP, which are in contact with the vertical portions of the channel patterns CP, respectively. In an embodiment, the upper conductive patterns UCP, which are connected to the lower conductive vias LVP, may be formed on the peripheral circuit region PCR, when the landing pads LP are formed.

[00160] The landing pads LP may be arranged to be spaced apart from each other, as shown in FIG. 3 or FIG. 7. The landing pads LP may have various shapes (e.g., circular, elliptical, rectangular, square, lozenge, and hexagonal shapes), when viewed in a plan view.

[00161] After the formation of the landing pads LP and the upper conductive patterns UCP, the third insulating patterns 165 may be formed to fill regions between the landing pads LP and the upper conductive patterns UCP.

[00162] Next, referring to FIGS. 3, 4A, and 4B, the etch stop layer 171 may be formed to cover the top surfaces of the landing pads LP and the upper conductive patterns UCP.

[00163] The data storage patterns DSP may be formed on the landing pads LP, respectively. In the case where the data storage pattern DSP includes a capacitor, bottom electrodes, a capacitor dielectric layer, and a top electrode may be sequentially formed. Here, the bottom electrodes may be formed to penetrate the etch stop layer 171 and may be connected to the landing pads LP, respectively.

[00164] After the formation of the data storage patterns DSP, the fourth insulating layer 173 may be formed to cover the top surface of the semiconductor substrate 100. The upper conductive vias UVP may be formed on the peripheral circuit region PCR to penetrate the fourth insulating layer 173 and may be coupled to the upper conductive patterns UCP.

[00165] By way of summation and review, an embodiment provides a semiconductor memory device with improved electric characteristics and an increased integration density. That is, according to an embodiment, a channel pattern and word lines, which are formed to have mirror

symmetry, may be used to realize vertical channel transistors. Accordingly, it may be possible to increase an integration density of a semiconductor memory device.

[00166] Since the mirror-symmetric channel pattern is formed using a deposition method, it may be possible to prevent a void or seam from being formed in the channel pattern. This may make it possible to improve electric and reliability characteristics of the transistor.

[00167] Since the word lines are formed to have an L-shaped section, it may be possible to increase effective channel lengths of the vertical channel transistors. By using a spacer when a pair of word lines are formed on the channel pattern, it may be possible to prevent or suppress the word lines from being exposed to an etching process.

[00168] Furthermore, since an oxide semiconductor material is used as the channel pattern, it may be possible to reduce a leakage current of a transistor. In addition, since peripheral circuits are vertically overlapped with a cell array, the integration density of the semiconductor memory device may be increased.

[00169] Example embodiments have been disclosed herein, and although specific terms are employed, they are used and are to be interpreted in a generic and descriptive sense only and not for purpose of limitation. In some instances, as would be apparent to one of ordinary skill in the art as of the filing of the present application, features, characteristics, and/or elements described in connection with a particular embodiment may be used singly or in combination with features, characteristics, and/or elements described in connection with other embodiments unless otherwise specifically indicated. Accordingly, it will be understood by those of skill in the art that various changes in form and details may be made without departing from the spirit and scope of the present invention as set forth in the following claims.

CLAIMS

1. A semiconductor memory device, comprising:

a bit line;

a channel pattern on the bit line, the channel pattern including a horizontal channel portion, which is provided on the bit line, and a vertical channel portion, which is vertically extended from the horizontal channel portion;

a word line provided on the channel pattern to cross the bit line, the word line including a horizontal portion, which is provided on the horizontal channel portion, and a vertical portion, which is vertically extended from the horizontal portion to face the vertical channel portion; and

a gate insulating pattern between the channel pattern and the word line.

2. The semiconductor memory device as claimed in claim 1, wherein:

the horizontal portion of the word line has a first thickness from a top surface of the horizontal channel portion, and

the vertical portion of the word line has a second thickness from a side surface of the vertical channel portion, the second thickness being equal to the first thickness.

3. The semiconductor memory device as claimed in claim 1 or claim 2, wherein:

the bit line extends lengthwise in a first direction and has a first width in a second direction, and

the horizontal channel portion of the channel pattern has a second width in the second direction, the second width being larger than the first width.

4. The semiconductor memory device as claimed in any one of claims 1 to 3, wherein a side surface of the horizontal channel portion of the channel pattern is aligned with a side surface of the horizontal portion of the word line.

5. The semiconductor memory device as claimed in any one of claims 1 to 3, further comprising a spacer on the word line, the spacer being aligned with a side surface of the horizontal portion of the word line.

6. The semiconductor memory device as claimed in claim 5, wherein a side surface of the horizontal channel portion of the channel pattern is aligned with the spacer.

7. The semiconductor memory device as claimed in claim 1, further comprising a mold insulating pattern on the bit line and in parallel to the word line, a side surface of the vertical channel portion of the channel pattern being in contact with the mold insulating pattern.

8. The semiconductor memory device as claimed in claim 1 or claim 2, wherein:
the bit line extends lengthwise in a first direction and has a predetermined width in a second direction,

the horizontal portion of the word line has a first horizontal width in the first direction,
and

the horizontal channel portion of the channel pattern has a second horizontal width in the first direction, the second horizontal width being larger than the first horizontal width.

9. The semiconductor memory device as claimed in claim 1 or claim 2, wherein:
the bit line extends lengthwise in a first direction and has a predetermined width in a second direction, and

the horizontal portion of the word line has a first horizontal width in the first direction, the first horizontal width being smaller than half a length of the horizontal channel portion in the first direction.

10. The semiconductor memory device as claimed in any one of claims 1 to 9, further comprising:

a landing pad connected to the vertical channel portion of the channel pattern, the landing pad being vertically spaced apart from a top surface of the vertical portion of the word line; and

a data storage pattern on the landing pad.

11. The semiconductor memory device as claimed in any one of claims 1 to 10, wherein the channel pattern includes an oxide semiconductor material.

12. A semiconductor memory device, comprising:

a bit line extending in a first direction;

a channel pattern on the bit line, the channel pattern including first and second vertical channel portions, which are opposite to each other, and a horizontal channel portion, which connects the first and second vertical channel portions to each other;

first and second word lines on the horizontal channel portion, the first and second word lines being symmetric with respect to each other, and each of the first and second word lines including a horizontal portion, which is provided on the horizontal channel portion, and a vertical portion, which is vertically extended from the horizontal portion to face a corresponding one of the first and second vertical channel portions; and

a gate insulating pattern between the channel pattern and each of the first and second word lines.

13. The semiconductor memory device as claimed in claim 12, further comprising a mold insulating pattern on the bit line, the mold insulating pattern having a trench extended in a second direction crossing the first direction,

wherein the first and second word lines are in the trench,

wherein the first vertical channel portion of the channel pattern is in contact with a first side surface of the trench, and

wherein the second vertical channel portion of the channel pattern is in contact with a second side surface of the trench.

14. The semiconductor memory device as claimed in claim 12 or claim 13, wherein the gate insulating pattern includes:

a first gate insulating pattern between the first word line and the channel pattern; and

a second gate insulating pattern between the second word line and the channel pattern, the second gate insulating pattern being spaced apart from the first gate insulating pattern.

15. The semiconductor memory device as claimed in claim 12 or claim 13, further comprising:

a first spacer on the first word line, the first spacer being aligned with a side surface of the horizontal portion of the first word line; and

a second spacer on the second word line, the second spacer being aligned with a side surface of the horizontal portion of the second word line.

16. The semiconductor memory device as claimed in claim 15, wherein the gate insulating pattern includes:

a first gate insulating pattern between the first word line and the channel pattern, a side surface of the first gate insulating pattern being aligned with the first spacer; and

a second gate insulating pattern between the second word line and the channel pattern, the second gate insulating pattern being spaced apart from the first gate insulating pattern, and a side surface of the second gate insulating pattern being aligned with the second spacer.

17. The semiconductor memory device as claimed in claim 15 or claim 16, further comprising a gap-fill insulating pattern between the first and second spacers.

18. The semiconductor memory device as claimed in any one of claims 12 to 17, wherein a portion of the horizontal channel portion of the channel pattern is between the first and second word lines.

19. The semiconductor memory device as claimed in any one of claims 12 to 18, further comprising:

landing pads connected to the first and second vertical channel portions of the channel pattern, the landing pads being vertically spaced apart from top surfaces of the vertical portions of the first and second word lines; and

data storage patterns on the landing pads.

20. A semiconductor memory device, comprising:

a peripheral circuit structure including peripheral circuits on a semiconductor substrate and a lower insulating layer covering the peripheral circuits;

bit lines on the peripheral circuit structure, the bit lines extending in a first direction;

a mold insulating pattern having trenches, the trenches extending in a second direction to cross the bit lines;

channel patterns spaced apart from each other in the second direction in each of the trenches, each of the channel patterns including:

first and second vertical channel portions opposite to each other, and

a horizontal channel portion connecting the first and second vertical channel portions to each other;

a first word line and a second word line extending in the second direction in each of the trenches, each of the first word line and the second word line including:

a horizontal portion, and

a vertical portion extending from the horizontal portion in a third direction perpendicular to the first direction and the second direction;

a first spacer on the first word line;
a second spacer on the second word line;
a gate insulating pattern between the channel patterns and the first and second word lines, the gate insulating pattern extending in the second direction;
landing pads on the first and second vertical channel portions of the channel patterns, respectively; and
data storage patterns on the landing pads, respectively.