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(54) **METHOD OF FABRICATING SEMICONDUCTOR DEVICE**

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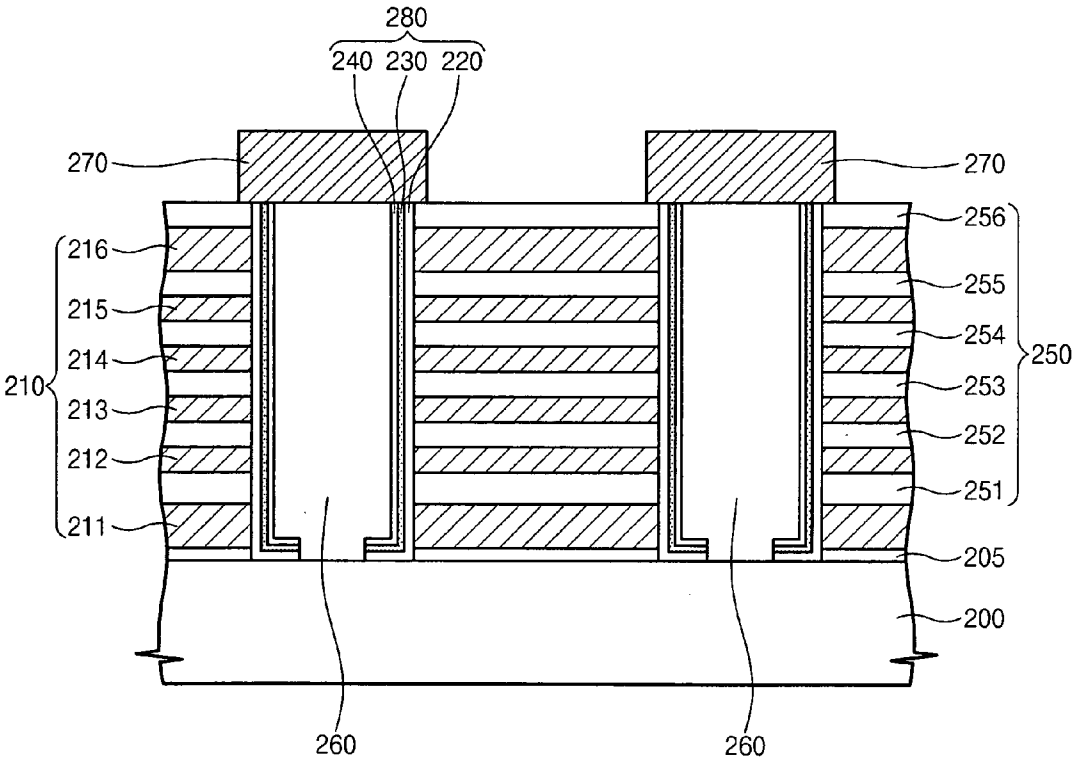
(57) **ABSTRACT**

A method of fabricating a semiconductor device including forming a charge storage layer, and forming a first tunnel insulating layer covering the charge storage layer, the forming of the first tunnel insulating layer including heat treating the charge storage layer.



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IPR2025-01281 (Sandisk Technologies, Inc. v. Longitude Flash Memory Solutions Ltd.)

Fig. 1A

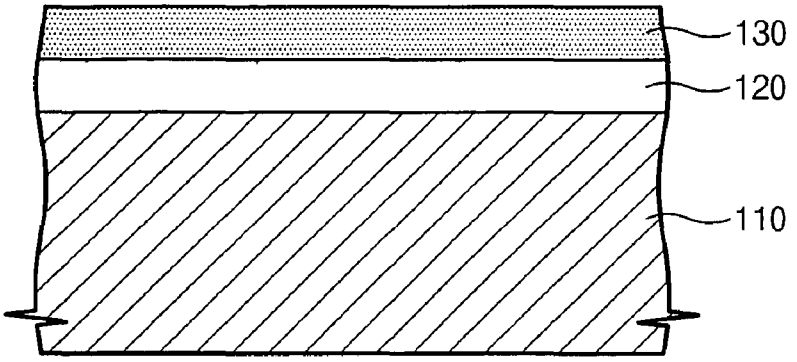

Fig. 1B

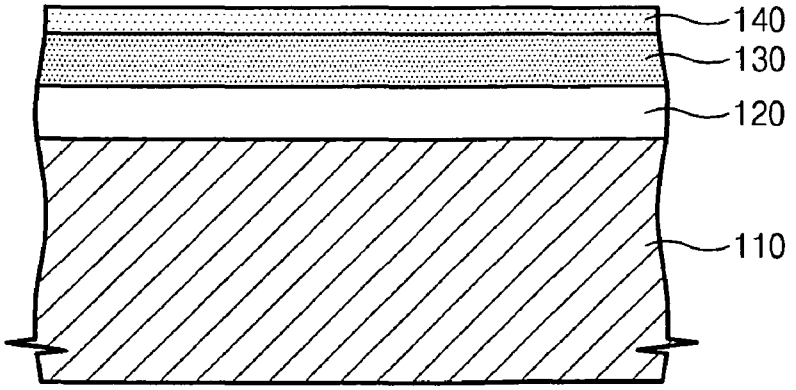

Fig. 1C

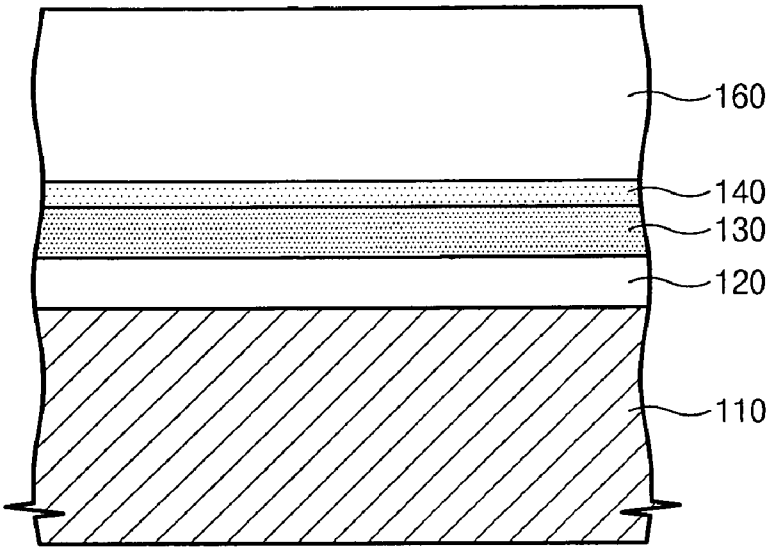

Fig. 2A

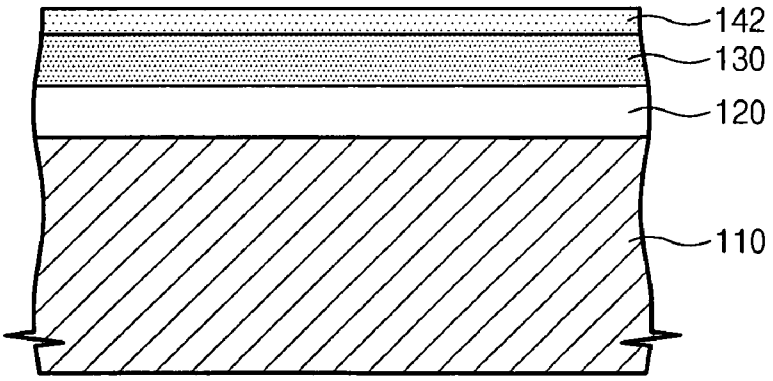

Fig. 2B

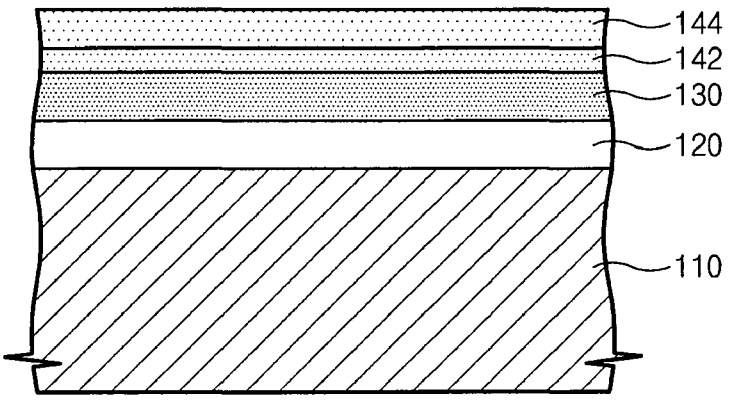

Fig. 2C

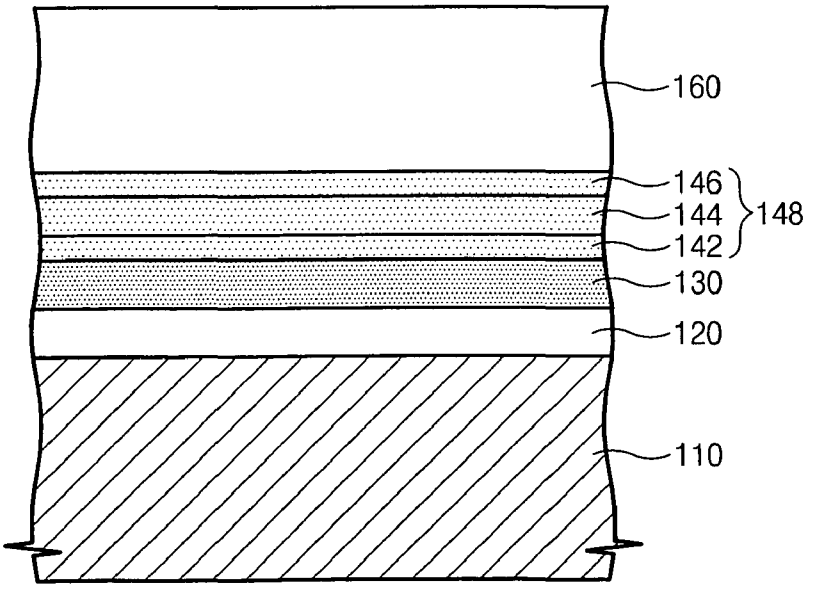

Fig. 3

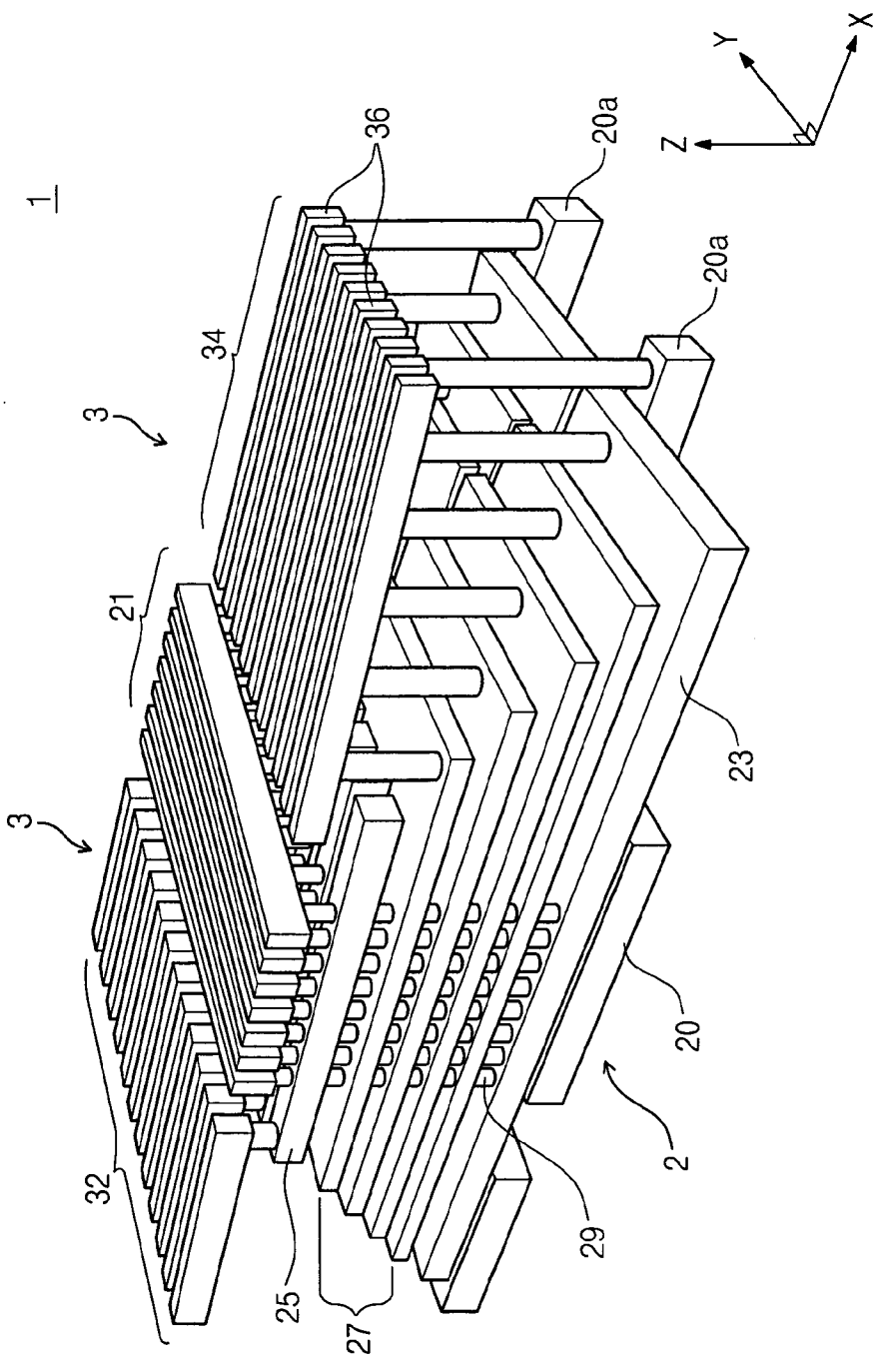

Fig. 4

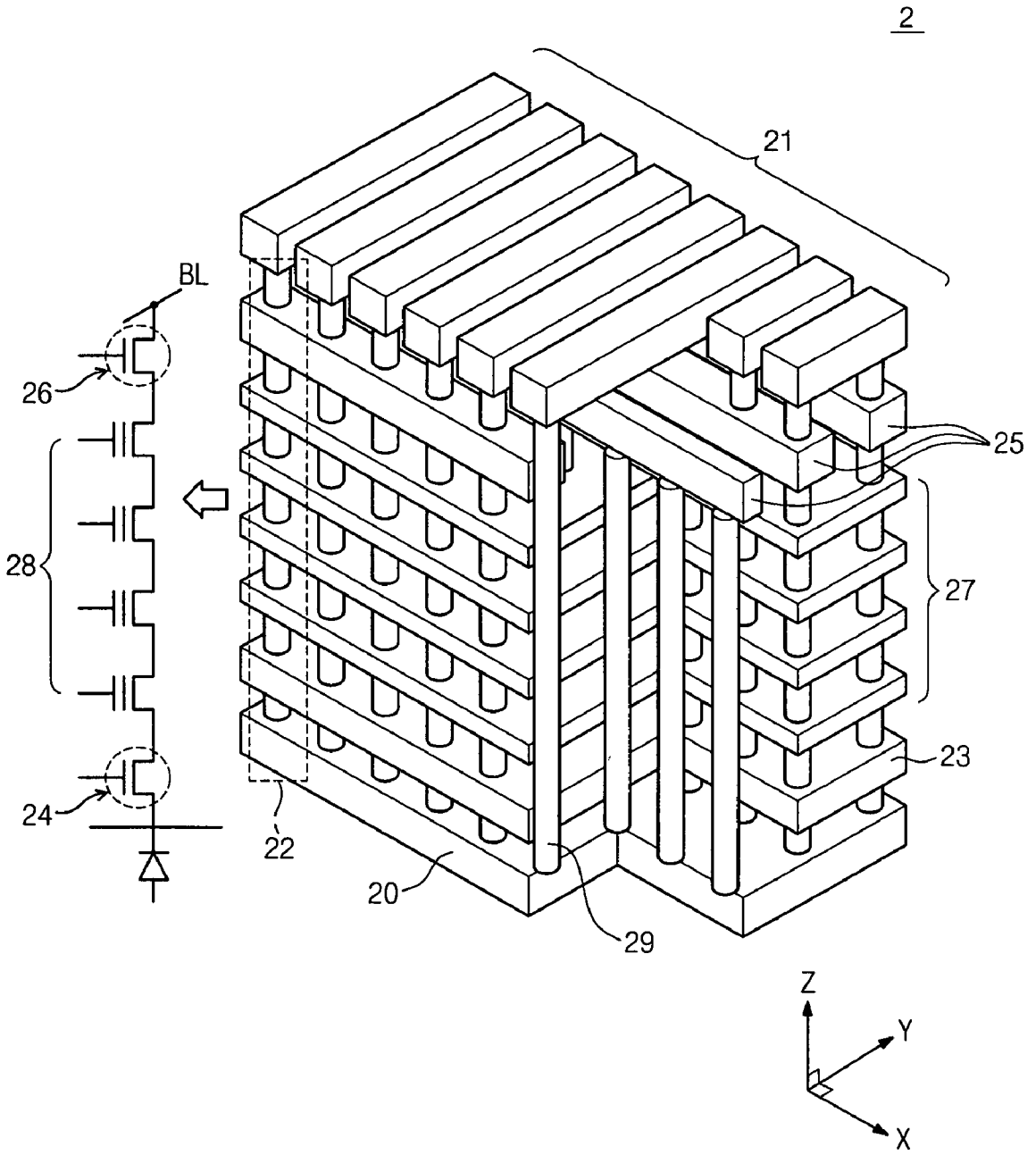

Fig. 5

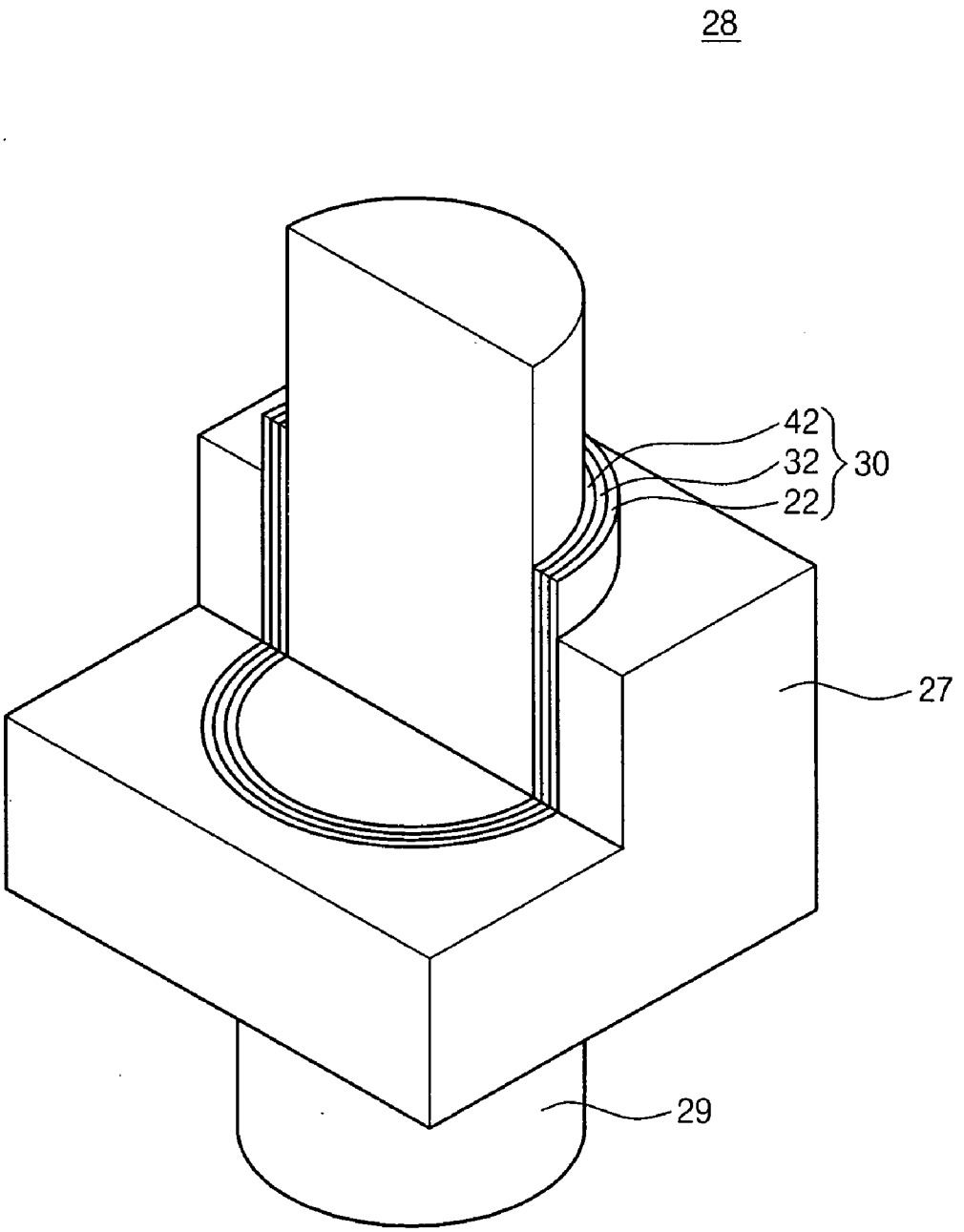

Fig. 6

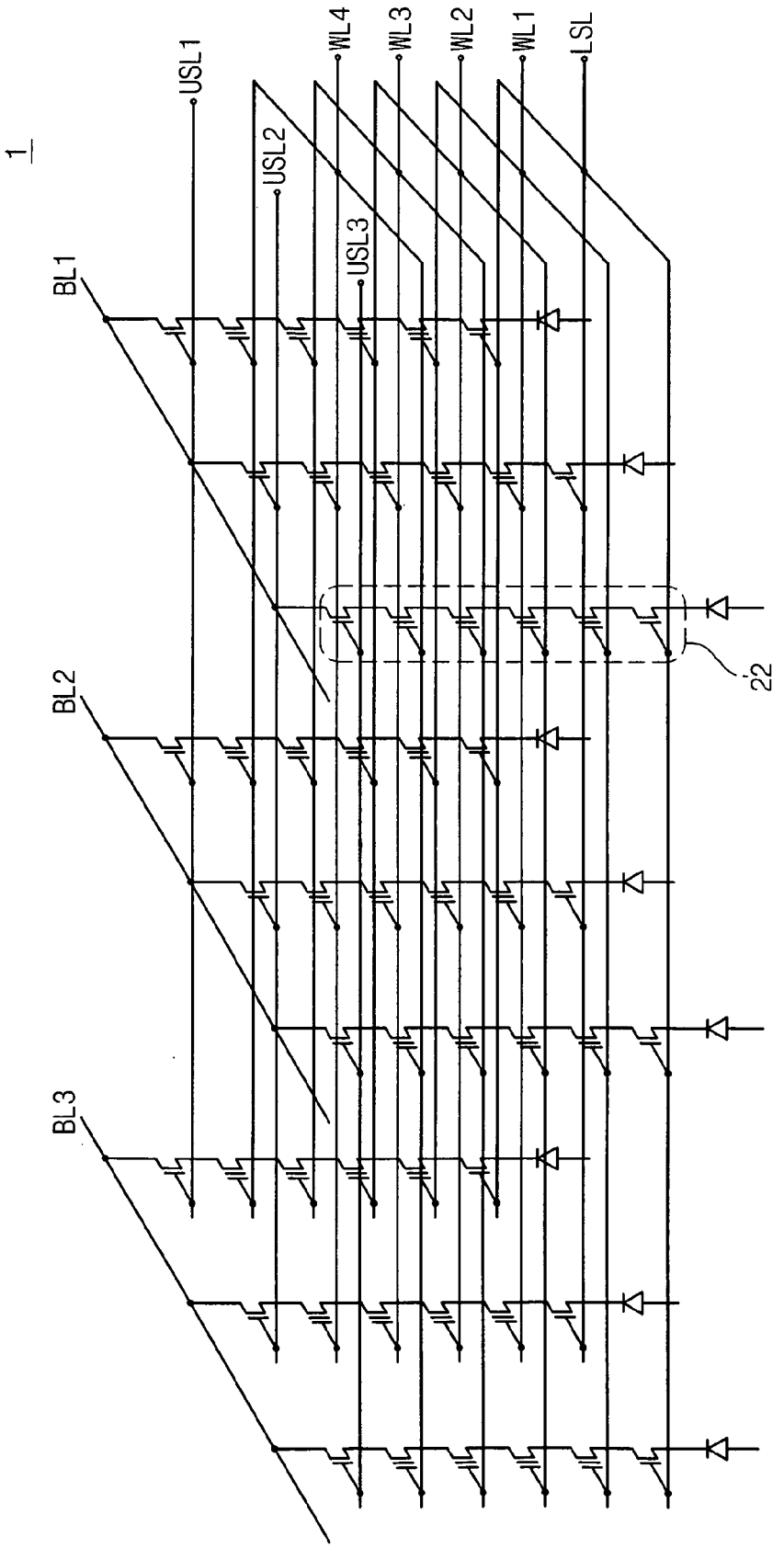

Fig. 7A

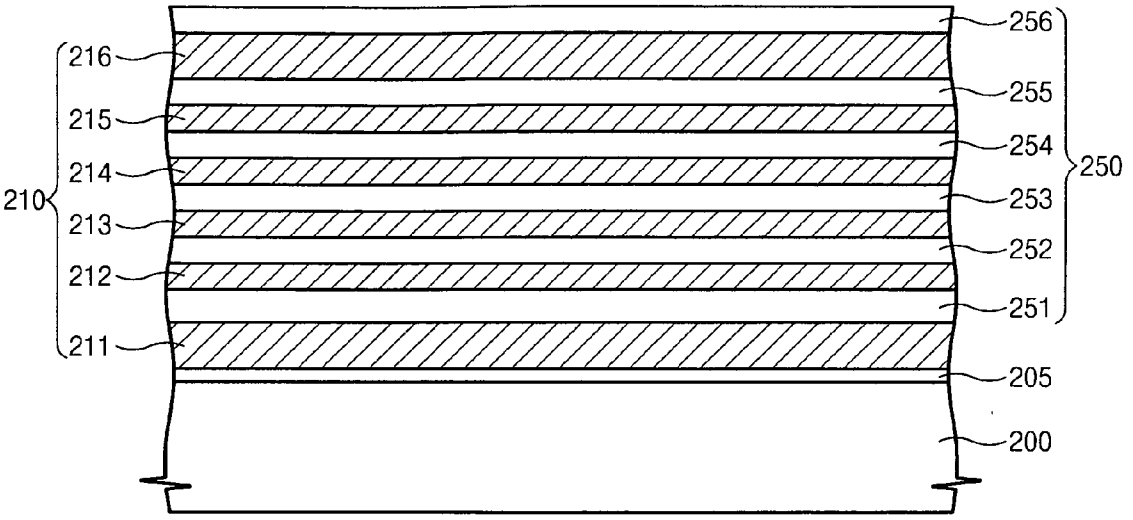

Fig. 7B

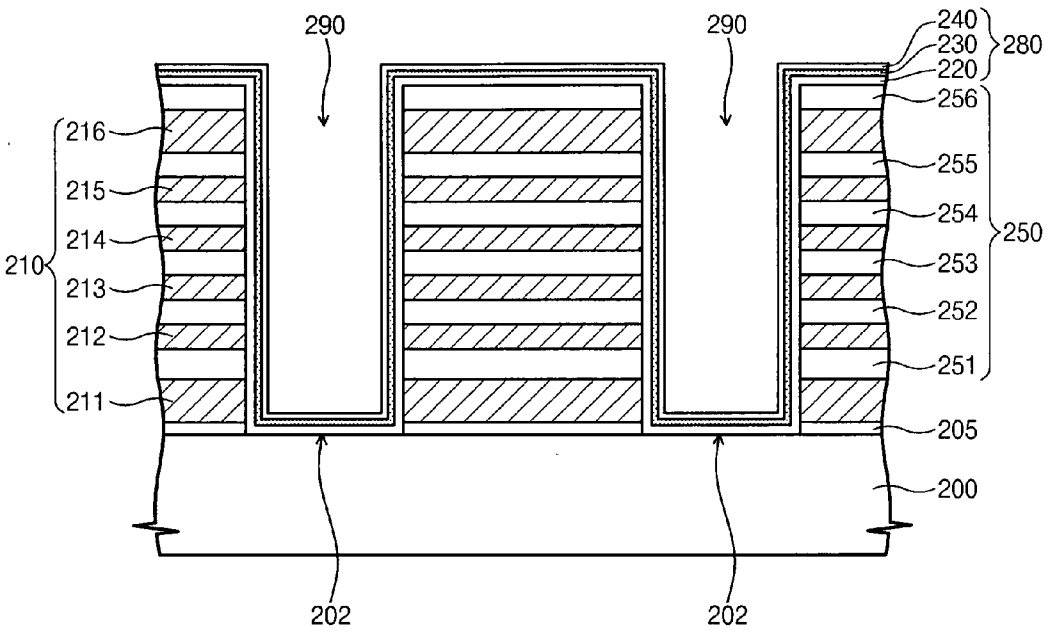
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Fig. 7C

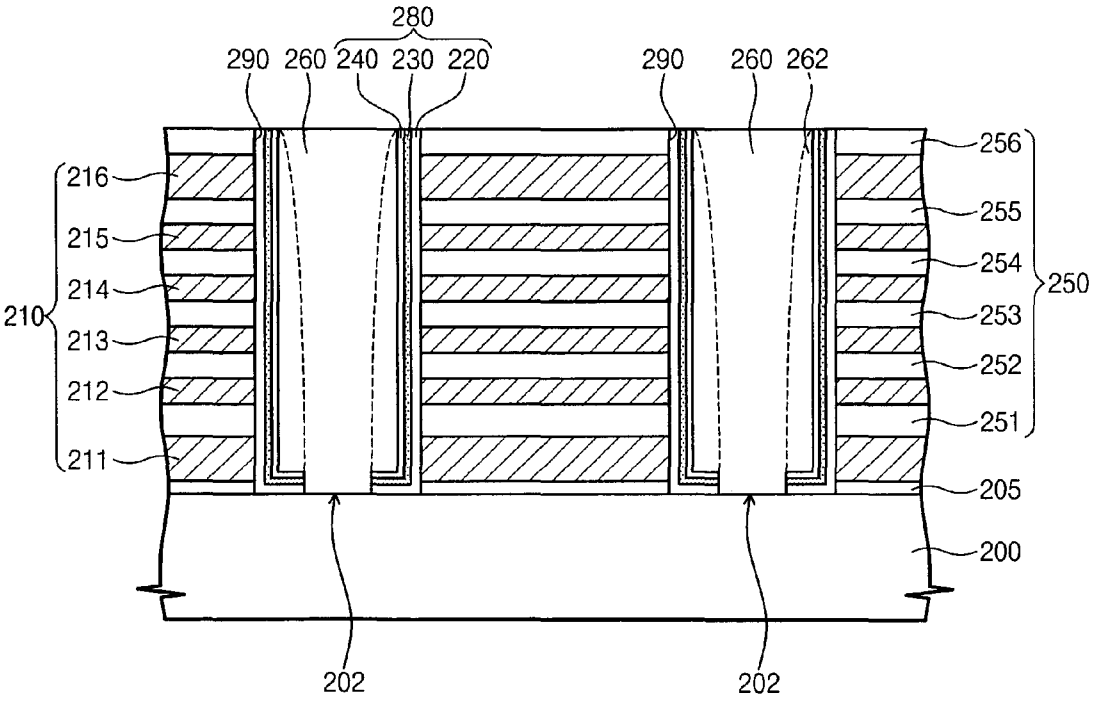
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Fig. 7D

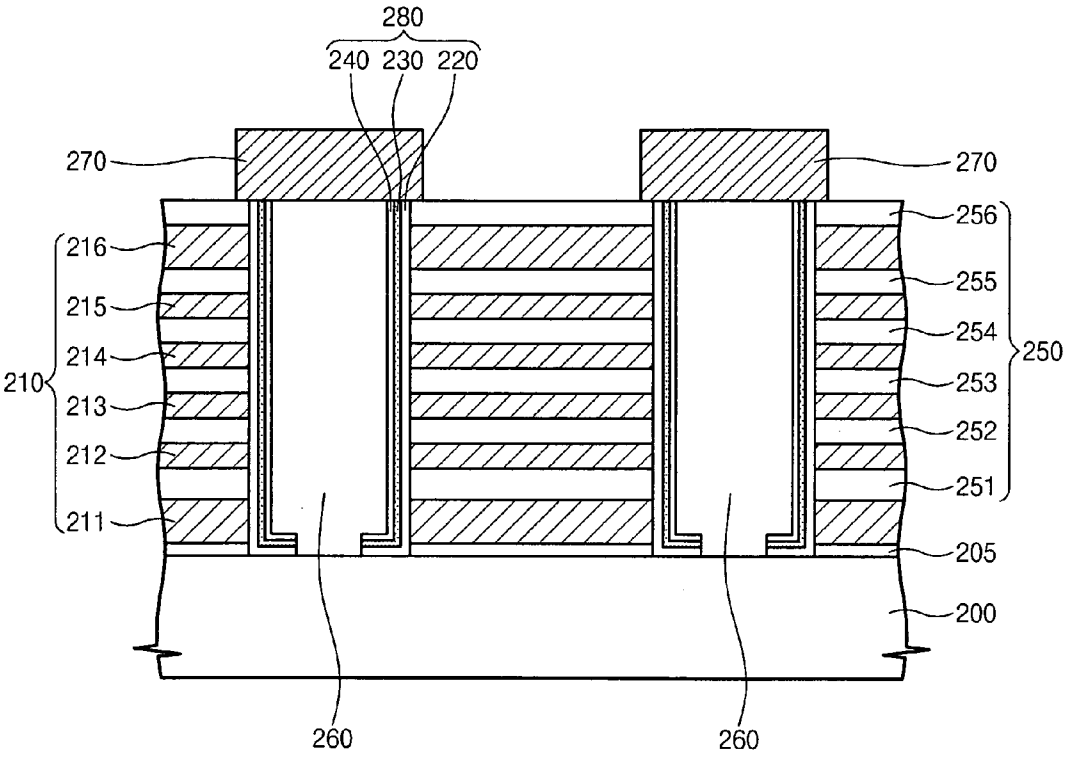
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Fig. 8

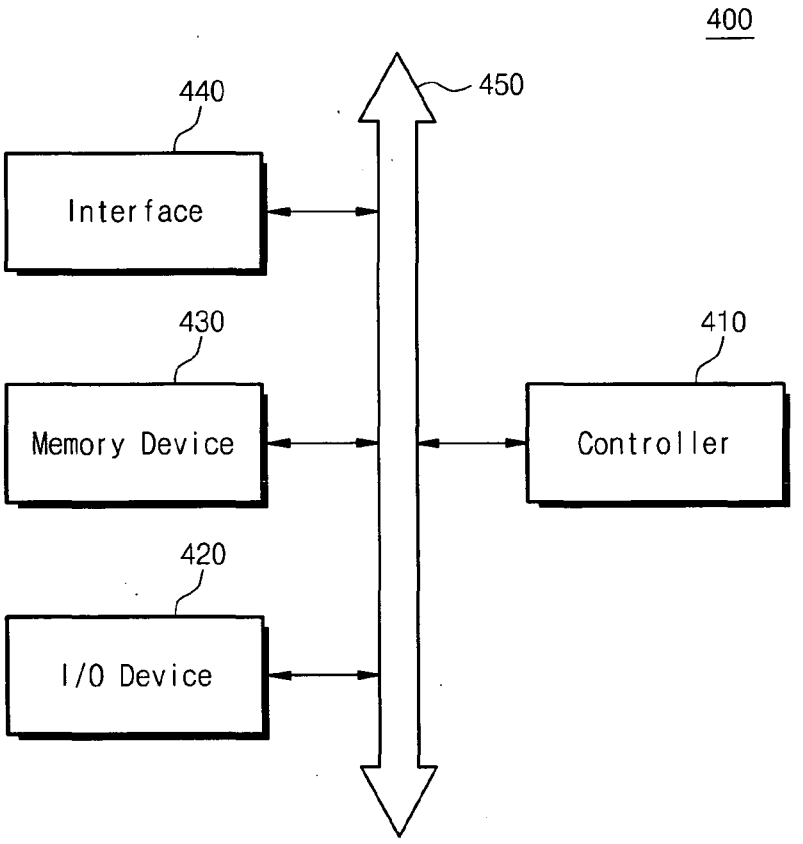
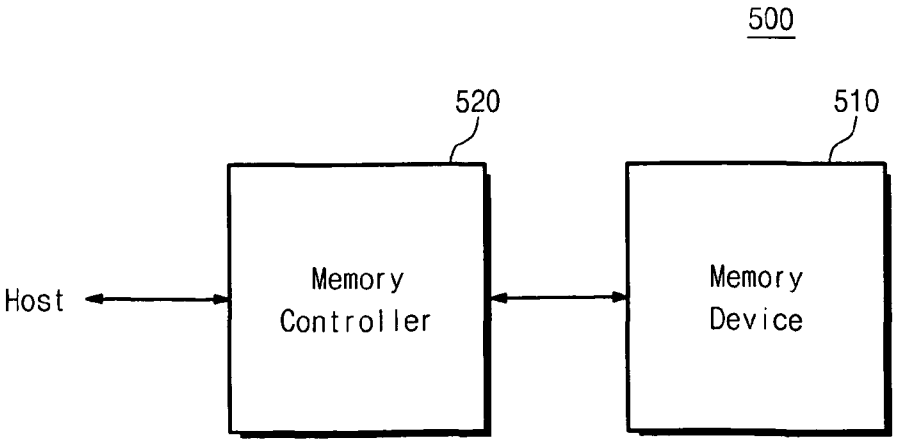

400
440
450
Interface
430
410
Memory Device
Controller
420
I/O Device

Fig. 9


500
520
510
Host
Memory Controller
Memory Device

METHOD OF FABRICATING SEMICONDUCTOR DEVICE

BACKGROUND

[0001] 1. Field

[0002] Embodiments relate to a method of fabricating a semiconductor device.

[0003] 2. Description of the Related Art

[0004] Recently, the integration degree of semiconductor devices has increased in order to achieve high performance and low cost in response to user's needs. In memory semiconductor devices, since the integration degree may be a significant factor for determining costs, an increase in the integration degree is especially important. In traditional two-dimensional, i.e., planar memory semiconductor devices, because the integration degree is determined by an area occupied by a unit memory cell, the technique used for forming fine patterns may have a great influence on the integration degree. However, since hyper-fine patterns may require high-priced equipment, while the integration degree of two-dimensional memory semiconductor devices is increasing, the increases are very limited. As alternatives for overcoming these limitations, developments have been made regarding techniques for forming three-dimensionally memory cells.

SUMMARY

[0005] Embodiments are directed to a method of fabricating a semiconductor device, which represents advances over the related art.

[0006] It is a feature of an embodiment to provide a method of fabricating a semiconductor device including a tunnel insulating layer.

[0007] It is another feature of an embodiment to provide a method of fabricating a semiconductor device having a three-dimensional structure.

[0008] At least one of the above and other features and advantages may be realized by providing a method of fabricating a semiconductor device including forming a charge storage layer, and forming a first tunnel insulating layer covering the charge storage layer, the forming of the first tunnel insulating layer including heat treating the charge storage layer.

[0009] The charge storage layer may include at least one of a silicon nitride layer and a polysilicon layer.

[0010] The heat treating the charge storage layer may include one of an oxidation process or a nitriding process.

[0011] The oxidation process may include at least one of a radical oxidation and wet oxidation. The nitriding process may include at least one of a plasma nitration and thermal nitration.

[0012] The method may further include forming a first semiconductor layer covering the charge storage layer such that the first semiconductor layer includes amorphous silicon or crystalline silicon, the heat treating the charge storage layer being performed after the forming of the first semiconductor layer.

[0013] The method may further include forming a gate layer, and forming a blocking insulating layer covering the gate layer, the forming of the charge storage layer including covering the blocking insulating layer with the charge storage layer.

[0014] The method may further include forming an active layer covering the first tunnel insulating layer, forming a second tunnel insulating layer interposed between the first tunnel insulating layer and the active layer, and forming a third tunnel insulating layer interposed between the second tunnel insulating layer and the active layer.

[0015] The forming of the second tunnel insulating layer may include performing one of an oxidation process or a nitriding process on the first tunnel insulating layer.

[0016] The forming of the second tunnel insulating layer may include depositing a second semiconductor layer on the first tunnel insulating layer, and performing an oxidation process on the second semiconductor layer.

[0017] The forming of the second tunnel insulating layer may include depositing one of a silicon oxide layer, a silicon nitride layer, or a high-k dielectric layer.

[0018] The forming of the third tunnel insulating layer may include performing one of an oxidation process or a nitriding process on the second tunnel insulating layer.

[0019] The forming of the third tunnel insulating layer may include depositing a third semiconductor layer on the second tunnel insulating layer, and performing an oxidation process on the third semiconductor layer.

[0020] At least one of the above and other features and advantages may also be realized by providing a method of fabricating a semiconductor device including alternately forming conductive layers and insulating layers on a substrate, forming an opening penetrating the conductive layers and the insulating layers, such that at least a portion of the substrate is exposed, forming a blocking insulating layer at a sidewall of the opening, forming a charge storage layer covering the blocking insulating layer, forming a tunnel insulating layer covering the charge storage layer after forming the charge storage layer, the tunnel insulating layer being formed by a heat treatment, and forming an active portion after forming the tunnel insulating layer, the active portion filling the opening.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] The above and other features and advantages will become more apparent to those of ordinary skill in the art by describing in detail exemplary embodiments with reference to the attached drawings, in which:

[0022] FIGS. **1**A to **1**C illustrate cross-sectional views of stages in a method of fabricating a semiconductor device according to an embodiment;

[0023] FIGS. **2**A to **2**C illustrate cross-sectional views of stages in a method of fabricating a semiconductor device according to a another embodiment;

[0024] FIG. **3** illustrates a perspective view of a semiconductor device according to an embodiment;

[0025] FIG. **4** illustrates a perspective view of a cell region of FIG. **3**;

[0026] FIG. **5** illustrates a perspective view of a memory transistor of FIG. **4**;

[0027] FIG. **6** illustrates an equivalent circuit view of a part of a semiconductor device according to an embodiment;

[0028] FIGS. **7**A to **7**D illustrate cross-sectional views of stages in a method of fabricating a semiconductor device according to yet another embodiment;

[0029] FIG. **8** illustrates a block diagram of an electronic system including a semiconductor device according to an embodiment; and

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[0030] FIG. **9** illustrates a block diagram of a memory card including a semiconductor device according to an embodiment.

DETAILED DESCRIPTION

[0031] Korean Patent Application No. 10-2009-0001979, filed on Jan. 9, 2009; in the Korean Intellectual Property Office, and entitled: "Method of Fabricating Semiconductor Device," is incorporated by reference herein in its entirety.

[0032] Example embodiments will now be described more fully hereinafter with reference to the accompanying drawings; however, they may be embodied in different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art.

[0033] In the drawing figures, the dimensions of layers and regions may be exaggerated for clarity of illustration. It will also be understood that when a layer or element is referred to as being "on" another layer or substrate, it can be directly on the other layer or substrate, or intervening layers may also be present. In addition, it will also be understood that when a layer is referred to as being "between" two layers, it can be the only layer between the two layers, or one or more intervening layers may also be present. Like reference numerals refer to like elements throughout.

[0034] It will be understood that, although the terms "first", "second", and so on may be used herein to describe each of the components, these components should not be limited by these terms. These terms are only used to distinguish one component from another component.

[0035] Hereinafter, a semiconductor device, e.g., a resistance variable memory device, and a method of forming the semiconductor device, e.g., the resistance variable memory device, according to an embodiment will be described in conjunction with the accompanying drawings.

[0036] FIGS. **1**A to **1**C illustrate cross-sectional views of stages in a method of fabricating a semiconductor device according to an embodiment: Referring to FIG. **1**A, a gate layer **110** may be formed. The gate layer **110** may include a conductive material, e.g., polysilicon and/or metal. A blocking insulating layer **120** may be formed on the gate layer **110**. A charge storage layer **130** may be formed on the blocking insulating layer **120**. The charge storage layer **130** may include a material capable of trapping charges, e.g., silicon nitride and/or polysilicon.

[0037] Referring to FIG. **1**B, a tunnel insulating layer **140** may be formed on the charge storage layer **130** by, e.g., a heat treatment. The tunnel insulating layer **140** may include, e.g., a silicon oxide layer and/or a silicon-nitride-oxide layer. The heat treatment may include, e.g., an oxidation process and/or a nitriding process. The oxidation process may include at least one of a radical oxidation and wet oxidation. The nitriding process may include at least one of a plasma nitration and thermal nitration.

[0038] Alternatively, a semiconductor layer (not illustrated) may be deposited on the charge storage layer **130**. The deposited semiconductor layer may then be converted into the tunnel insulating layer **140** by the heat treatment. The semiconductor layer may include, e.g., amorphous silicon and/or crystalline silicon. The tunnel insulating layer **140** may include, e.g., a silicon oxide layer. The heat treatment may include, e.g., an oxidation process.

[0039] In contrast to a method of forming the tunnel insulating layer on a silicon substrate by the oxidation process or the nitriding process in a gate stack structure of a two-dimensional memory semiconductor device, the present embodiment may provide a method of forming the tunnel insulating layer **140** applicable to a reverse gate stack structure. The reverse gate stack structure may be formed by sequentially stacking the gate layer **110**, the blocking insulating layer **120**, the charge storage layer **130**, and the tunnel insulating layer **140**.

[0040] Referring to FIG. **1**C, an active layer **160** may be formed on the tunnel insulating layer **140**. The active layer **160** may include, e.g., crystalline silicon.

[0041] FIGS. **2**A to **2**C illustrate cross-sectional views of stages in a method of fabricating a semiconductor device according to another embodiment. Because the present embodiment is similar to the above-described embodiment, repeated description of duplicated technical features are omitted.

[0042] Referring to FIG. **2**A, the gate layer **110**, the blocking insulating layer **120**, the charge storage layer **130**, and a first tunnel insulating layer **142** may be stacked sequentially in the same manner as described with respect to FIG. **1**A and FIG. **1**B.

[0043] Referring to FIG. **2**B, a second tunnel insulating layer **144** may be formed on the first tunnel insulating layer **142**. In an implementation, the second tunnel insulating layer **144** may be formed by an oxidation or nitriding process of the first tunnel insulating layer **142**. The second tunnel insulating layer **144** may include, e.g., a silicon oxide layer and/or a silicon-nitride-oxide layer.

[0044] In another implementation, a first semiconductor layer (not illustrated) may be deposited on the first tunnel insulating layer **142**. The first semiconductor layer deposited on the first tunnel insulating layer **142** may be converted into the second tunnel insulating layer **144** by an oxidation process. The first semiconductor layer may include, e.g., amorphous silicon and/or crystalline silicon.

[0045] In yet another implementation, the second tunnel insulating layer **144** may be formed on the first tunnel insulating layer **142** by depositing thereon, e.g., a silicon oxide layer, a silicon nitride layer, and/or a high-k layer.

[0046] Referring to FIG. **2**C, a third tunnel insulating layer **146** may be formed on the second tunnel insulating layer **144**. In an implementation, the third tunnel insulating layer **146** may be formed by an oxidation or nitriding process of the second tunnel insulating layer **144**. The third tunnel insulating layer **146** may include, e.g., a silicon oxide layer and/or a silicon-nitride-oxide layer.

[0047] In another implementation, a second semiconductor layer may be deposited on the second tunnel insulating layer **144**. The second semiconductor layer deposited on the second tunnel insulating layer **144** may be converted into the third tunnel insulating layer **146** by an oxidation process. The second semiconductor layer may include, e.g., amorphous silicon and/or crystalline silicon.

[0048] In still another implementation, the third tunnel insulating layer **146** may be formed on the second tunnel insulating layer **144** by depositing thereon, e.g., a silicon oxide layer and/or a silicon nitride layer.

[0049] The first to third tunnel insulating layers **142**, **144**, and **146** together may be used as a charge tunneling layer **148**. In an implementation, one layer, or a combination of two layers, of the first to third tunnel insulating layers **142**, **144**,

and **146** may be used as the charge tunneling layer **148**. According to the present embodiment, the first to third tunnel insulating layers **142**, **144**, and **146** may have different oxygen concentration gradients and/or nitrogen concentration gradients from one another. Moreover, the second tunnel insulating layer **144** may have a higher dielectric constant than the first tunnel insulating layer **142** and the third tunnel insulating layer **146**.

[0050] FIG. **3** illustrates a perspective view of a semiconductor device according to an embodiment. Referring to FIG. **3**, a semiconductor device **1** may include a cell region **2** having memory cells and a peripheral region **3** having a peripheral circuit for operating the memory cells. The configuration of the semiconductor device **1** according to an embodiment will be described below. An example is disclosed in U.S. Patent Application Publication No. 2007-0252201, which is incorporated by reference herein in its entirety.

[0051] The cell region **2** may be vertically stacked on a semiconductor substrate **20** in a Z-direction. The cell region **2** may include a plurality of plate-shaped control gates **27** forming an X-Y plane, an upper selective gate **25**, a lower selective gate **23**, a plurality of bit lines **21**, and a plurality of active portions **29**. The upper selective gate **25** and the lower selective gate **23** may be stacked on upper and lower parts of the plurality of control gates **27**, respectively. The plurality of bit lines **21** may be stacked on the upper selective gate **25** and may extend in a Y-direction. The plurality of active portions **29** may extend vertically in the Z-direction on the semiconductor substrate **20**. Each of the active portions **29** may extend from the semiconductor substrate **20** to the bit lines **21**, penetrating the upper and lower selective gate **23** and **25** and the control gate **27**. The semiconductor substrate **20** may be, e.g., a P-type silicon substrate. In this case, the active portions **29** may be formed on a N+ region of the P-type silicon substrate. Alternatively, the N+ region may not be formed between the semiconductor substrate **20** and the active portion **29**.

[0052] One of the lower selective gate **23** and the upper selective gate **25** may have a plate shape forming the X-Y plane, and the other may have a line shape extending in an X-direction. Alternatively, both the lower selective gate **23** and the upper selective gate **25** may have a line shape extending in the X-direction. In an implementation, the lower selective gate **23** may have the plate shape forming the X-Y plane, and the upper selective gate **25** may have the line shape extending in the X-direction.

[0053] The peripheral region **3** may include an upper selective line driving circuit **32** connected to the plurality of upper selective gates **25**, a word line driving circuit **34** connected to the plurality of control gates **27**, and a common source line **36** connected to a source **20***a* of the semiconductor substrate **20**. The source **20***a* may be of a different conductive type from the semiconductor substrate **20**. For example, when the conductive type of the semiconductor substrate **20** is P-type, the conductive type of the source **20***a* may be N-type.

[0054] FIG. **4** illustrates a perspective view of the cell region of FIG. **3**. FIG. **5** illustrates a perspective view of a memory transistor of FIG. **4**. Referring to FIGS. **4** and **5**, a plurality of memory transistors **28** may be defined by the active portions **29** and the control gates **27**. A lower selective transistor **24** may be defined by the active portions **29** and the lower selective gate **23**. An upper selective transistor **26** may be defined by the active portions **29** and the upper selective gate **25**. The semiconductor device may be, e.g., a NAND flash memory device, that forms one cell string **22** by connecting the plurality of memory transistors **28** to the upper and lower selective transistors **26** and **24** in series. In an implementation, one cell string **22** may include four memory transistors **28**. However, the number of memory transistors **28** in one cell string **22** may be arbitrarily changed depending on desired memory capacities. The active portions **29** may have an arbitrary pillar shape, e.g., a cylindrical shape having a circular cross-section or a rectangle shape having a rectangular cross-section.

[0055] In an implementation, the memory transistors **28** and the upper and lower selective transistors **26** and **24** may be depletion mode transistors in which a source and drain do not exist in the active portions **29**. In another implementation, the memory transistors **28** and the upper and lower selective transistors **26** and **24** may be enhancement mode transistors in which a source and drain do exist in the active portions **29**.

[0056] The plurality of active portions **29** may have a Z-directional axis penetrating the plurality of control gates **27**. Thus, intersection points of the plurality of control gates **27** with the plurality of active portions **29** may be distributed three-dimensionally. In other words, the memory transistors **28** of the semiconductor device may be respectively formed at the three-dimensionally distributed intersection points. A gate insulating layer **30** may be disposed between the plurality of active portions **29** and the plurality of control gates **27**. The gate insulating layer **30** may include a blocking insulating layer **22**, a charge storage layer **32**, and a tunnel insulating layer **42**. The blocking insulating layer **22**, charge storage layer **32**, and tunnel insulating layer **42** may be formed by the same method as described above with reference to FIGS. **1** and **2**.

[0057] FIG. **6** illustrates an equivalent circuit view of a part of the semiconductor device according to an embodiment. Referring to FIGS. **1** to **6**, in the semiconductor device **1**, the plurality of control gates **27** may be used as a plurality of word lines WL**1** to WL**4**, the plurality of upper selective gates **25** may be used as a plurality of upper selective lines USL**1** to USL**3**, and the lower selective gate **23** may be used as a lower selective line LSL. The cell string **22** may be connected to each of the bit lines BL**1** to BL**3**.

[0058] Since each of the control gates **27** may form a flat-plate structure that spreads out two-dimensionally, each of the word lines WL**1** to WL**4** may have a plane structure and may be substantially perpendicular to the cell string **22**. The plurality of memory transistors **28** may be distributed three-dimensionally in the plurality of word lines WL**1** to WL**4**.

[0059] Since the upper selective gate **25** may form a separated wiring structure extending in the X-direction, the plurality of upper selective lines USL**1** to USL**3** may intersect the plurality of bit lines BL**1** to BL**3**. Each of the upper selective lines USL**1** to USL**3** may be electrically connected to each of the bit lines BL**1** to BL**3**. Accordingly, each cell string **22** may be independently selected.

[0060] Since the lower selective gate **23** may form a flat-plate structure that spreads out two-dimensionally, the lower selective line LSL may have a plane structure and may be substantially perpendicular to the cell string **22**. The lower selective line LSL may control an electrical connection between the active portion **29** and the semiconductor substrate **20**.

[0061] In the semiconductor device **1**, a program operation may include setting a voltage difference between a selected word line WL and active portion **29** and injecting charges into

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the charge storage layer of the memory transistor **28**. In an implementation, the program may include applying program voltage Vprog to the selected word line WL and injecting electrons from the active portion **29** into the charge storage layer **32** of the memory transistor **28** corresponding to the desired word line WL intended to program, using Fowler-Nordenheim (FN) tunneling. Since the memory transistor **28**, which corresponds to a non-selected word line, may be programmed by the program voltage applied to the selected word line WL, a boosting technology may be used to prevent an inadvertent program.

[0062] A reading operation may be performed by setting the word line WL connected to the desired memory transistor **28** to 0V and by setting another word line to read voltage Vread. Thus, it may be determined whether current is charged in the bit line BL depending on whether or not a threshold voltage Vth of the memory transistor **28** intended to be read is greater than an existing voltage. Accordingly, data information of the desired memory transistor **28** may be read by sensing the current of the corresponding bit line BL.

[0063] An erasing operation may be performed for each block using, e.g., a Gate-Induced Drain Leakage (GIDL) current. An erase voltage Verase may be applied to the selected bit line BL and the semiconductor substrate **200**, thereby raising the potential of the active portion **29**. In an implementation, the potential of the active portion **29** may rise slowly. The GIDL may be generated at a terminal of the lower selective gate **24**, electrons generated by the GIDL may be emitted into the semiconductor substrate **20**, and the generated holes may be emitted into the active portion **29**. Thus, the potential in the vicinity of the erase voltage Verase may be transmitted to the channel of the memory transistor **28**, i.e., the active portion **29**. If the potential of the word line WL is set to 0V, the electrons stored in the memory transistor **28** may be emitted, thereby erasing the data. Meanwhile, an inadvertent erasing operation may be prevented by floating the word line of the non-selected block.

[0064] The method of operating the semiconductor device **1** described above is not limited thereto. Accordingly, it will be apparent to those skilled in the art that various modifications and changes may easily be embodied on the basis of the known technical. For example, the operation of the semiconductor device **1** may be embodied in the same way as disclosed in U.S. Patent Application Publication No. 2007-0252201, which has been incorporated by reference herein.

[0065] FIGS. **7**A to **7**D illustrate cross-sectional views of stages in a method of fabricating a semiconductor device according to another embodiment. Referring to FIG. **7**A, a semiconductor substrate **200** may be provided. The semiconductor substrate **200** may be formed of a single-crystalline semiconductor, e.g., a p-type silicon wafer. The semiconductor substrate **200** may include regions, e.g., well regions, which are electrically isolated from one another by other conductive-type impurity regions. The well regions may have, e.g., a pocket well structure or a triple well structure. An etch stop layer **205** may be formed on the semiconductor substrate **200**. The etch stop layer **205** may include, e.g., a silicon oxide layer. The etch stop layer **205** may be used as, e.g., a capacitor dielectric layer.

[0066] A conductive layer group **210** and an insulating layer group **250** may be formed on the etch stop layer **205**. The conductive layer group **210** may include a plurality of conductive layers **211**, **212**, **213**, **214**, **215**, and **216**. The insulating layer group **250** may include a plurality of insulating layers **251**, **252**, **253**, **254**, **255**, and **256**. The conductive layers **211** to **216** and the insulating layers **251** to **256** may be alternately formed. The conductive layers **211** to **216** may be formed by, e.g., depositing a doped polycrystalline silicon and/or metal. The lowermost conductive layer **211** may serve as a lower selective gate. The uppermost conductive layer **216** may serve as an upper selective gate. The conductive layers **212**, **213**, **214**, and **215** between the lowermost conductive layer **211** and the uppermost conductive layer **216** may serve as control gates. The conductive layers **212** to **215** may have the same thickness. The thickness of the conductive layers **212** to **215** may be selected to, e.g., avoid an undesirable short channel effect.

[0067] The insulating layers **251** to **256** may be formed by depositing on an adjoining layer or substrate, e.g., a silicon oxide layer. Alternatively, the insulating layers **251** to **256** may be formed of, e.g., a high-k dielectric layer. In an implementation, the insulating layers **251** to **256** may be formed by depositing materials on an adjoining layer or substrate, e.g., silicon nitride and/or silicon oxynitride, having a higher dielectric constant than a silicon oxide layer.

[0068] With respect to layers forming the insulating layer group **250** and the conductive layer group **210**, the number of layers, the thickness of the layers, and the materials of the layers may be varied in view of desired electrical characteristics and technical difficulty in a process for patterning the layers. The insulating layer group **250** and the conductive layer group **210** may have a stair-type structure.

[0069] Referring to FIG. **7**B, openings **290** may be formed by patterning the conductive layer group **210** and the insulating layer group **250** to expose a portion of the semiconductor substrate **200**. The openings **290** may be formed using, e.g., a dry etching process, to have vertical sidewalls, thereby realizing uniform electrical characteristics of a resultant transistor. The patterning process may be performed until the etch stop layer **205** is removed. The openings **290** may expose an upper surface **202** of the semiconductor substrate **200**. The sidewalls of the openings **290** may include exposed sidewalls of the conductive layers **211** to **216** in the conductive layer group **210**.

[0070] A gate insulating layer **280** may be formed at the sidewalls of the openings **290** to cover the exposed sidewalls of the conductive layers **211** to **216**. The gate insulating layer **280** may include a blocking insulating layer **220**, a charge storage layer **230**, and a tunnel insulating layer **240**. The blocking insulating layer **220**, the charge storage layer **230**, and the tunnel insulating layer **240** may be laterally stacked in the same way or in a similar way as described above with reference to FIGS. **1** and **2**. That is, the method of forming the tunnel insulating layer **240** according to the previous embodiment may be applied to a gate structure of a three-dimensional semiconductor memory device.

[0071] Referring to FIG. **7**C, spacers **262** may be formed at the sidewalls of the openings **290**. A portion of the gate insulating layer **280** may be etched using the spacers **262** as an etch mask, thereby exposing an upper surface **202** of the semiconductor substrate **200**. The spacers **262** may be formed on the gate insulating layer **280** in the openings **290** to cover inner sidewalls thereof. The spacers **262** may, e.g., reduce damage to the gate insulating layer **280** during the etching process for exposing the upper surface **202** of the semiconductor substrate **200**.

[0072] Active portions **260** may fill the openings **290**. The active portions **260** and the semiconductor substrate **200** may

include a same material. The active portions **260** may grow from the exposed upper surface **202** of the semiconductor substrate **200** by, e.g., an epitaxial process. In an implementation, the semiconductor substrate **200** and the active portions **260** may be single-crystalline silicon without a crystal defect. When the spacers **262** are formed of silicon, the spacers **262** may be single-crystallized during the epitaxial process to form a portion of the active portions **260**. The active portions **260** may have the same conductive type as the semiconductor substrate **200**. For example, both the semiconductor substrate **200** and the active portions **260** may be P-type. Thus, since a diode is not configured between the active portions **260** and the semiconductor substrate **200**, the active portions **260** may have the same equipotential as the semiconductor substrate **200**.

[0073] Referring to FIG. **7**D, bit lines **270** may be formed on the active portions **260**. The bit lines **270** may be electrically connected to the active portions **260**. Furthermore, the bit line **270** may extend in a direction intersecting the upper selective gate.

[0074] FIG. **8** illustrates a block diagram of an electronic system including the semiconductor device according to an embodiment. Referring to FIG. **8**, an electronic system **400** may include a controller **410**, an input and output (I/O) device **420**, and a memory device **430**. The controller **410**, the I/O device **420**, and the memory device **430** may be coupled to each other via a bus **450**. The bus **450** may be a transfer pathway of data and/or operation signals. The controller **410** may include at least one of a microprocessor, a digital signal process, and a microcontroller, and at least one logic device that can execute functions similar to these. The I/O device **420** may include at least one of a keypad, a keyboard, and a display device. The memory device **430** may store data and/or instructions to be executed by the controller **410**. The memory device **430** may include a semiconductor memory device according to an embodiment. The electronic system **400** may further include an interface **440** for, e.g., transmitting data to a communication network or receiving data from a communication network. The interface **440** may be, e.g., wired or wireless. The interface **440** may include, e.g., an antenna or a wired/wireless transceiver.

[0075] The electronic system **400** may include, e.g., a mobile system, personal computer, industrial computer, and/or system carrying out various functions. The mobile system may include, e.g., a personal digital assistant (PDA), portable computer, web tablet, mobile phone, wireless phone, laptop computer, memory card, digital music system, and/or information transmitting/receiving system. The electronic system **400** may be used in a communication interface protocol of 3 G communication system, e.g., CDMA, GSM, NADC, E-TDMA, WCDAM, and/or CDMA2000, when the electronic system **400** constitutes equipment capable of carrying out wireless communications.

[0076] FIG. **9** illustrates a block diagram of a memory card including a semiconductor device according to an embodiment. Referring to FIG. **9**, a memory card **500** may include a memory device **510** and a memory controller **520**. The memory device **510** may store data. Preferably, the memory device **510** has non-volatile characteristics for retaining the stored data in its entirety even if a power source is interrupted. The memory device **510** may include the semiconductor memory device according to an embodiment. The memory controller **520** may read out data stored in the memory device **510** and/or may store data in the memory device **510** in response to a read/write request from a host.

[0077] Furthermore, the memory device **510**, e.g., a flash memory device or flash memory system, may be mounted by various types of packages. The flash memory device or the flash memory system may be packaged and mounted as, e.g., Package on Package (PoP), Ball Grid Arrays (BGAs), Chip Scale Packages (CSPs), Plastic Leaded Chip Carrier (PLCC), Plastic Dual In-Line Package (PDIP), Multi Chip Package (MCP), Wafer Level Package, Wafer-level Fabricated Package (WFP), Wafer-Level Processed Stack Package (WSP), Die in Waffle Pack, Die in Wafer Form, Chip On Board (COB), Ceramic Dual In-Line Package (CERDIP), Plastic Metric Quad Flat Pack (MQFP), Thin Quad Flat pack (TQFP), Small Outline Package (SOIC), Shrink Small Outline Package (SSOP), Thin Small Outline Package (TSOP), Thin Quad Flat Package (TQFP), System In Package (SIP), and the like.

[0078] According to an embodiment, the method of forming the tunnel insulating layer may be applicable to the reverse gate stack structure. In addition, the method of forming the tunnel insulating layer may be applicable to the three-dimensional semiconductor memory structure.

[0079] Exemplary 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. Accordingly, it will be understood by those of ordinary 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.

What is claimed is:

1. A method of fabricating a semiconductor device, comprising:
- forming a charge storage layer; and
- forming a first tunnel insulating layer covering the charge storage layer,
- the forming of the first tunnel insulating layer including heat treating the charge storage layer.

2. The method as claimed in claim **1**, wherein the charge storage layer includes at least one of a silicon nitride layer and a polysilicon layer.

3. The method as claimed in claim **1**, wherein the heat treating the charge storage layer includes at least one of an oxidation process and a nitriding process.

4. The method as claimed in claim **3**, wherein the oxidation process includes at least one of a radical oxidation and wet oxidation, wherein the nitriding process includes at least one of a plasma nitration and thermal nitration.

5. The method as claimed in claim **1**, further comprising:
- forming a first semiconductor layer covering the charge storage layer such that the first semiconductor layer includes amorphous silicon or crystalline silicon,
- the heat treating the charge storage layer being performed after the forming of the first semiconductor layer.

6. The method as claimed in claim **1**, further comprising:
- forming a gate layer; and
- forming a blocking insulating layer covering the gate layer,
- the forming of the charge storage layer including covering the blocking insulating layer with the charge storage layer.

7. The method as claimed in claim **1**, further comprising:
- forming an active layer covering the first tunnel insulating layer;
- forming a second tunnel insulating layer interposed between the first tunnel insulating layer and the active layer; and

forming a third tunnel insulating layer interposed between the second tunnel insulating layer and the active layer.

8. The method as claimed in claim **7**, wherein the forming of the second tunnel insulating layer includes performing one of an oxidation process or a nitriding process on the first tunnel insulating layer.

9. The method as claimed in claim **7**, wherein the forming of the second tunnel insulating layer includes:

depositing a second semiconductor layer on the first tunnel insulating layer, and

performing an oxidation process on the second semiconductor layer.

10. The method as claimed in claim **7**, wherein the forming of the second tunnel insulating layer includes depositing one of a silicon oxide layer, a silicon nitride layer, or a high-k dielectric layer.

11. The method as claimed in claim **7**, wherein the forming of the third tunnel insulating layer includes performing one of an oxidation process or a nitriding process on the second tunnel insulating layer.

12. The method as claimed in claim **7**, wherein the forming of the third tunnel insulating layer includes:

depositing a third semiconductor layer on the second tunnel insulating layer, and

performing an oxidation process on the third semiconductor layer.

13. A method of fabricating a semiconductor device, comprising:

alternately forming conductive layers and insulating layers on a substrate;

forming an opening penetrating the conductive layers and the insulating layers, such that at least a portion of the substrate is exposed;

forming a blocking insulating layer at a sidewall of the opening;

forming a charge storage layer covering the blocking insulating layer;

forming a tunnel insulating layer covering the charge storage layer after forming the charge storage layer, the tunnel insulating layer being formed by a heat treatment; and

forming an active portion after forming the tunnel insulating layer, the active portion filling the opening.

14. The method as claimed in claim **13**, wherein the heat treating the charge storage layer includes at least one of an oxidation process and a nitriding process.

15. The method as claimed in claim **13**, further comprising:

forming a first semiconductor layer covering the charge storage layer such that the first semiconductor layer includes amorphous silicon or crystalline silicon,

the heat treating the charge storage layer being performed after the forming of the first semiconductor layer.

16. The method as claimed in claim **13**, further comprising:

forming an active layer covering the first tunnel insulating layer;

forming a second tunnel insulating layer interposed between the first tunnel insulating layer and the active layer; and

forming a third tunnel insulating layer interposed between the second tunnel insulating layer and the active layer.

17. The method as claimed in claim **16**, wherein the forming of the second tunnel insulating layer includes performing one of an oxidation process or a nitriding process on the first tunnel insulating layer.

18. The method as claimed in claim **16**, wherein the forming of the second tunnel insulating layer includes:

depositing a second semiconductor layer on the first tunnel insulating layer, and

performing an oxidation process on the second semiconductor layer.

19. The method as claimed in claim **16**, wherein the forming of the second tunnel insulating layer includes depositing one of a silicon oxide layer, a silicon nitride layer, or a high-k dielectric layer.

20. The method as claimed in claim **16**, wherein the forming of the third tunnel insulating layer includes:

depositing a third semiconductor layer on the second tunnel insulating layer, and

performing an oxidation process on the third semiconductor layer.

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