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NONVOLATILE MEMORY DEVICES

Abstract

A nonvolatile memory device includes a memory cell array and a row decoder. The memory cell array includes a plurality of mats. A first cell string of first mat is connected to a plurality of first word-lines, a first bit-line and a first string selection line. A second cell string of second mat is connected to a plurality of second word-lines, a second bit-line and a second string selection line. Each of the first and second cell strings includes a ground selection transistor, memory cells, and a string selection transistor coupled in series. The row decoder applies a first voltage to a third word-line among the plurality of first and second word-lines for a first period of time in a single mat mode and to apply a second voltage to the third word-line for a second period of time longer than the first period of time in a multi-mat mode.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This U.S. Non-provisional application is a Continuation of U.S. patent application Ser. No. 18/581,018, filed on Feb. 19, 2024, now Allowed, which is a Continuation of U.S. patent application Ser. No. 17/958,386, filed on Oct. 1, 2022, U.S. Pat. No. 11,942,140, which is a Continuation of U.S. patent application Ser. No. 17/321,393, filed on May 14, 2021, U.S. Pat. No. 11,462,260, which is a Continuation of U.S. patent application Ser. No. 16/991,693, filed on Aug. 12, 2020, U.S. Pat. No. 11,017,838, which is a continuation-in-part application of U.S. patent application Ser. No. 16/817,951 filed on Mar. 13, 2020, U.S. Pat. No. 10,777,254, which is a Continuation of U.S. patent application Ser. No. 16/675,331, filed on Nov. 6, 2019, U.S. Pat. No. 10,672,454, which is a Continuation of U.S. patent application Ser. No. 16/183,315, filed on Nov. 7, 2018, U.S. Pat. No. 10,629,254, which is a Divisional Application of U.S. patent application Ser. No. 15/604,406 filed on May 24, 2017, U.S. Pat. No. 10,153,029, which claims priority under 35 USC § 119 to Korean Patent Application No. 10-2016-0099219, filed on Aug. 4, 2016, in the Korean Intellectual Property Office (KIPO), the disclosure of each of which is incorporated herein by reference in its entirety.

BACKGROUND

1. Technical Field

[0002] Exemplary embodiments relate generally to semiconductor memory devices, and more particularly to nonvolatile memory devices and memory systems.

2. Discussion of the Related Art

[0003] Semiconductor memory devices may be typically classified into volatile semiconductor

memory devices and nonvolatile semiconductor memory devices. Volatile semiconductor memory devices may perform read and write operations at a high speed, while contents stored therein may be lost when the devices are powered-off. Nonvolatile semiconductor memory devices may retain contents stored therein even when powered-off. For this reason, nonvolatile semiconductor memory devices may be used to store contents to be retained regardless of whether the devices are powered on or off.

[0004] Nonvolatile semiconductor memory devices may include a mask read-only memory (MROM), a programmable ROM (PROM), an erasable programmable ROM (EPROM), an electrically erasable programmable ROM (EEPROM), etc.

[0005] A flash memory device may be a typical nonvolatile memory device. A flash memory device may be widely used as the voice and image storing media of electronic apparatuses such as a computer, a cellular phone, a PDA, a digital camera, a camcorder, a voice recorder, an MP3 player, a handheld PC, a game machine, a facsimile, a scanner, a printer, etc. For improving the performance of read/write operation of flash memory devices, flash memory devices may operate in a multi-mat mode. However, it is desired to reduce a load of word-lines or bit-lines of the flash memory devices operating in the multi-mat mode.

SUMMARY

[0006] Some exemplary embodiments are directed to a nonvolatile memory device, capable of enhancing performance.

[0007] Some exemplary embodiments are directed to provide a memory system, capable of enhancing performance.

[0008] According to exemplary embodiments, a nonvolatile memory device includes a memory cell array and a row decoder. The memory cell array includes a plurality of mats, and each of the plurality mats includes a plurality of cell strings. A first cell string of a first mat is connected to a plurality of first word-lines, a first bit-line and a first string selection line. A second cell string of a second mat is connected to a plurality of second word-lines, a second bit-line and a second string selection line. Each of the first and second cell strings includes at least one ground selection transistor, a plurality of memory cells, and at least one string selection transistor coupled in series. The row decoder connected to the plurality of first and second word-lines and the first and second string selection lines, applies corresponding word-line voltages to the plurality of first and second word-lines. The row decoder applies a first voltage to a third word-line among the plurality of first and second word-lines for a first period of time when a first operation of the nonvolatile memory device is performed for only one of the first and second mats and to apply a second voltage to the third word-line for a second period of time when the first operation is performed for both of the first and second mats simultaneously, and the second period of time is longer than the first period of time.

[0009] According to exemplary embodiments, a nonvolatile memory device includes a memory cell region including a first metal pad, a peripheral circuit region including a second metal pad and vertically connected to the memory cell region by the first metal pad and the second metal pad, a memory cell array in the memory cell region and a row decoder in the peripheral circuit region. The memory cell array includes a plurality of mats, and each of the plurality mats includes a plurality of cell strings. A first cell string of a first mat is connected to a plurality of first word-lines, a first bit-line and a first string selection line. A second cell string of a second mat is connected to a plurality of second word-lines, a second bit-line and a second string selection line. Each of the first and second cell strings includes at least one ground selection transistor, a plurality of memory cells, and at least one string selection transistor coupled in series. The row decoder connected to the plurality of first and second word-lines, the first and second string selection lines, applies corresponding word-line voltages to the plurality of first and second word-lines. The row decoder applies a first voltage to a third word-line among the plurality of first and second word-lines for a first period of time when a first operation of the nonvolatile memory device is performed

for only one of the first and second mats and to apply a second voltage to the third word-line for a second period of time when the first operation is performed for both of the first and second mats simultaneously, and the second period of time is different from the first period of time.

[0010] Accordingly, in a nonvolatile memory device according to exemplary embodiments, levels or application time intervals of the voltages applied to the memory cell array are differentiated in a single mat mode and a multi-mat mode, and performance in both the single mat mode and the multi-mat mode may be enhanced.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Illustrative, non-limiting exemplary embodiments will be more clearly understood from the following detailed description in conjunction with the accompanying drawings.

[0012] FIG. 1 is a block diagram illustrating a memory system according to exemplary embodiments.

[0013] FIG. 2 is a table illustrating control signals in the memory system of FIG. 1.

[0014] FIG. 3 is a block diagram illustrating the nonvolatile memory device in the memory system of FIG. 1 according to exemplary embodiments.

[0015] FIG. 4 is a block diagram illustrating the memory cell array in FIG. 3 according to exemplary embodiments.

[0016] FIG. 5 is a perspective view illustrating one of the memory blocks of FIG. 4 according to exemplary embodiments.

[0017] FIG. 6 is a circuit diagram illustrating a mat configuration in the nonvolatile memory device of FIG. 3 according to exemplary embodiments.

[0018] FIG. 7 is a block diagram illustrating the control circuit in the nonvolatile memory device of FIG. 3 according to exemplary embodiments.

[0019] FIG. 8 is a block diagram illustrating the voltage generator in the nonvolatile memory device of FIG. 3 according to exemplary embodiments.

[0020] FIG. 9 is a block diagram illustrating a row decoder in the nonvolatile memory device of FIG. 3 according to exemplary embodiments.

[0021] FIGS. 10 and 11 illustrate the word-line voltages or the bit-line voltages in the single mat mode and the multi-mat mode respectively, according to exemplary embodiments.

[0022] FIG. 12 illustrates the nonvolatile memory device of FIG. 3 according to exemplary embodiments.

[0023] FIG. 13 is a timing diagram illustrating the word-line voltages and the bit-line voltages applied to the first and second mats in the single mat mode and the multi-mat mode in FIG. 6 when a read operation is performed on the nonvolatile memory device of FIG. 3, according to exemplary embodiments.

[0024] FIG. 14 illustrates that one of the word-line voltages or one of the bit-line voltages in the single mat mode is over-driven in the multi-mat mode, according to exemplary embodiments.

[0025] FIG. 15 is a table illustrating setting values of levels and application time interval of the word-line voltages and the bit-line voltages applied to the first second mats in FIGS. 13 and 14 when a read operation is performed on the nonvolatile memory device of FIG. 3., according to exemplary embodiments

[0026] FIG. 16 is a timing diagram illustrating the word-line voltages and the bit-line voltages applied to the first and second mats in the single mat mode and the multi-mat mode in FIG. 6 when a program operation is performed on the nonvolatile memory device of FIG. 3, according to exemplary embodiments.

[0027] FIG. 17 is a table illustrating setting values of levels and application time interval of the

word-line voltages and the bit-line voltages applied to the first second mats in FIG. 16 when the program operation is performed on the nonvolatile memory device of FIG. 3, according to exemplary embodiments.

[0028] FIG. 18 is a block diagram illustrating a memory system according to exemplary embodiments.

[0029] FIG. 19 is a flow chart illustrating a method of nonvolatile memory device according to exemplary embodiments.

[0030] FIG. 20 is a block diagram illustrating a solid state disk or solid state drive (SSD) according to exemplary embodiments.

[0031] FIG. 21 is a block diagram of a memory device according to some embodiments.

[0032] FIG. 22 is a diagram schematically illustrating the structure of the memory device of FIG. 21 according to some example embodiments.

[0033] FIG. 23 is a diagram illustrating a row decoder and a pass transistor circuit in the memory device of FIG. 21 according to an example embodiment.

[0034] FIG. 24 is a diagram of the memory device including the pass transistor circuit in FIG. 23, according to some example embodiments.

[0035] FIG. 25 is a cross-sectional view taken along a line A-A' of FIG. 24, according to some example embodiments.

[0036] FIG. 26 is a cross-sectional view taken along a line B-B' of FIG. 24, according to some example embodiments.

[0037] FIGS. 27A through 27C are diagrams of memory devices including the pass transistor circuit in FIG. 23 respectively, according to example embodiments.

[0038] FIG. 28 is a cross-sectional view illustrating a memory device according to some embodiments.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0039] Various exemplary embodiments will be described more fully hereinafter with reference to the accompanying drawings, in which some exemplary embodiments are shown.

[0040] It will be understood that, although the terms first, second, third etc. may be used herein to describe various elements, these elements should not be limited by these terms. Unless indicated otherwise, these terms are generally used to distinguish one element from another. Thus, a first element discussed below in one section of the specification could be termed a second element in a different section of the specification without departing from the teachings of the present disclosure. Also, terms such as “first” and “second” may be used in the claims to name an element of the claim, even though that particular name is not used to describe in connection with the element in the specification. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items. Expressions such as that, although the terms first, second, third etc. may be used herein to describe various elements, these elements should be elements of the list.

[0041] Expressions such as “at least one of,” when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list.

[0042] FIG. 1 is a block diagram illustrating a memory system according to exemplary embodiments.

[0043] Referring to FIG. 1, a memory system (or a nonvolatile memory system) 10 may include a memory controller 20 and at least one nonvolatile memory device 30.

[0044] The memory system 10 may include data storage media based flash memory such as a memory card, a universal serial bus (USB) memory and solid state drive (SSD).

[0045] The nonvolatile memory device 30 may perform a read operation, an erase operation, and a program operation or a write operation under control of the memory controller 20. The nonvolatile memory device 30 receives a command CMD, an address ADDR and data DATA through input/output lines from the memory controller 20 for performing such operations. In addition, the nonvolatile memory device 30 receives a control signal CTRL through a control line from the

memory controller **20**. The nonvolatile memory device **30** receives a power PWR through a power line from the memory controller **20**.

[0046] The nonvolatile memory device **30** may include a memory cell array **100** and a decision circuit **520**. The memory cell array **100** may include at least a first mat MAT1 and a second mat MAT2. Each of the first mat MAT1 and the second mat MAT2 may include a plurality of memory blocks. Each block of the plurality of memory blocks may include a plurality of strings each string including a plurality of transistors connected to a plurality of word-lines and a plurality of bit-lines. The first mat MAT1 may be referred to as a first plane PLANE1 and the second mat MAT2 may be referred to as a second plane PLANE2. The decision circuit **520** may determine one of a single mat mode and a multi-mat mode of the first mat MAT1 and the second mat MAT2.

[0047] FIG. **2** is a table illustrating control signals in the memory system of FIG. **1**.

[0048] Referring to FIGS. **1** and **2**, the control signal CTRL, which the memory controller **20** applies to the nonvolatile memory device **30**, may include, a command latch enable signal CLE, an address latch enable signal ALE, a chip enable signal nCE, a read enable signal nRE, and a write enable signal nWE.

[0049] The memory controller **20** may transmit the command latch enable signal CLE to the nonvolatile memory device **30**. For example, the memory controller **20** may transmit the command latch enable signal CLE to the nonvolatile memory device **30** via a separately assigned control pin. The command latch enable signal CLE may be a signal indicating that information transferred via the input/output lines is a command.

[0050] The memory controller **20** may transmit the address latch enable signal ALE to the nonvolatile memory device **30**. The memory controller **20** may transmit the address latch enable signal ALE to the nonvolatile memory device **30** via a separately assigned control pin. The address latch enable signal ALE may be a signal indicating that information transferred via the input/output lines is an address.

[0051] The memory controller **20** may transmit the chip enable signal nCE to the nonvolatile memory device **30**. The memory controller **20** may transmit the chip enable signal nCE to the nonvolatile memory device **30** via a separately assigned control pin. The chip enable signal nCE may indicate a memory chip selected from among a plurality of memory chips when the nonvolatile memory device includes the plurality of memory chips. For example, the chip enable signal nCE may include one or more chip enable signals nCEs.

[0052] The memory controller **20** may transmit the read enable signal nRE to the nonvolatile memory device **30**. The memory controller **20** may transmit the read enable signal nRE to the nonvolatile memory device **30** via a separately assigned control pin. The nonvolatile memory device **30** may transmit read data to the memory controller **20** based on the read enable signal nRE.

[0053] The memory controller **20** may transmit the write enable signal nWE to the nonvolatile memory device **30**. The memory controller **20** may transmit the write enable signal nWE to the nonvolatile memory device **30** via a separately assigned control pin. When the write enable signal nWE is activated, the nonvolatile memory device **30** may store data input signals provided from the memory controller **20** to the memory cell array **100** of the nonvolatile memory device **30**.

[0054] FIG. **3** is a block diagram illustrating the nonvolatile memory device in the memory system of FIG. **1** according to exemplary embodiments.

[0055] Referring to FIG. **3**, the nonvolatile memory device **30** includes a memory cell array **100**, a row decoder **600**, a page buffer circuit **410**, a data input/output circuit **420**, a control circuit **500**, and a voltage generator **700** (e.g., a word-line voltage generator). The control circuit **500** may include the decision circuit **520**.

[0056] The memory cell array **100** may be coupled to the row decoder **600** through a string selection line SSL, a plurality of word-lines WLs, and a ground selection line GSL. In addition, the memory cell array **100** may be coupled to the page buffer circuit **410** through a plurality of bit-lines BLs.

[0057] The memory cell array **100** may include a plurality of memory cells coupled to the plurality of word-lines WLs and the plurality of bit-lines BLs.

[0058] In some exemplary embodiments, the memory cell array **100** may be a three-dimensional memory cell array, which is formed on a substrate in a three-dimensional structure (or a vertical structure). In this case, the memory cell array **100** may include vertical cell strings that are vertically oriented such that at least one memory cell is located over another memory cell. The following patent documents, which are hereby incorporated by reference, describe suitable configurations for three-dimensional memory cell arrays: U.S. Pat. Nos. 7,679,133; 8,553,466; 8,654,587; 8,559,235; and US Pat. Pub. No. 2011/0233648.

[0059] In other exemplary embodiments, the memory cell array **100** may be a two-dimensional memory cell array, which is formed on a substrate in a two-dimensional structure (or a horizontal structure).

[0060] Referring still to FIG. 3, the row decoder **600** may select at least one of a plurality of memory blocks of the plurality of mats of the cell array **100** in response to an address ADDR from the memory controller **20**. For example, the row decoder **600** may select at least one of a plurality of word-lines in the selected one or more memory blocks. The row decoder **600** may transfer a voltage (e.g., a word-line voltage) generated from the voltage generator **700** to a selected word-line. At a program operation, the row decoder **600** may transfer a program voltage or a verification voltage to a selected word-line and a pass voltage to an unselected word-line. At a read operation, the row decoder **600** may transfer a selection read voltage to a selected word-line and a non-selection read voltage to an unselected word-line.

[0061] The page buffer circuit **410** may operate as a write driver at a program operation and a sense amplifier at a read operation. At a program operation, the page buffer circuit **410** may provide a bit-line of the memory cell array **100** with a bit-line voltage corresponding to data to be programmed. At a read or verification read operation, the page buffer circuit **410** may sense data stored in a selected memory cell via a bit-line. The page buffer circuit **410** may include a plurality of page buffers PB1 to PBn each connected with one bit-line or two bit-lines.

[0062] The control circuit **500** may generate a plurality of control signals CTLs, a first control signal LTC1, and a second control signal LTC2 based on the command signal CMD. The control circuit **500** may also generate a row address R_ADDR and a column address C_ADDR based on the address signal ADDR. A detailed description for the control circuit **500** will be described later.

[0063] In example embodiments, the nonvolatile memory device **30** may further include a voltage generator (not shown) for supplying a variable voltage to a selected bit-line of the memory cell array **100** through the page buffer circuit **410**. In other example embodiments, the page buffer circuit **410** may include the voltage generator (not shown) applying a variable voltage to a selected bit-line of the memory cell array **100**.

[0064] FIG. 4 is a block diagram illustrating the memory cell array in FIG. 3 according to exemplary embodiments.

[0065] Referring to FIG. 4, the memory cell array **100** may include a plurality of memory blocks BLK1 to BLKz which extend in a plurality of directions D1, D2 and D3. In particular, each of the first mat MAT1 (or the first plane PLANE1) and the second mat MAT2 (or the second plane PLANE2) may include the plurality of memory blocks BLK1 to BLKz. In an embodiment, the memory blocks BLK1 to BLKz are selected by the row decoder **600** in FIG. 3. For one example, the row decoder **600** may select a particular memory block BLK corresponding to a block address among the memory blocks BLK1 to BLKz of one of the first and second mats MAT1 and MAT2. For another example, the row decoder **600** may select two particular memory blocks BLKs corresponding to a block address among the memory blocks BLK1 to BLKz of each of the first and second mats MAT1 and MAT2.

[0066] FIG. 5 is a perspective view illustrating one of the memory blocks of FIG. 4 according to exemplary embodiments.

[0067] Referring to FIG. 5, a memory block BLK_i includes structures extending along the first to third directions D1~D3.

[0068] A substrate **111** is provided. For example, the substrate **111** may have a well of a first type (e.g., a first conductive type). For example, the substrate **111** may have a p-well formed by implanting a group 3 element such as boron (B). For example, the substrate **111** may have a pocket p-well provided in an n-well. In an embodiment, the substrate **111** has a p-type well (or a p-type pocket well). However, the conductive type of the substrate **111** is not limited to the p-type.

[0069] A plurality of doping regions **311** to **314** extending along the first direction D1 are provided in/on the substrate **111**. For example, the plurality of doping regions **311** to **314** may have a second type (e.g., a second conductive type) different from the first type of the substrate **111**. In an embodiment, the first to fourth doping regions **311** to **314** have an n-type. However, the conductive type of the first to fourth doping regions **311** to **314** is not limited to the n-type.

[0070] A plurality of insulation materials **112** extending along the second direction D2 are sequentially provided along the third direction D3 on a region of the substrate **111** between the first and second doping regions **311** and **312**. For example, the plurality of insulation materials **112** are provided along the third direction D3, being spaced by a specific distance. Exemplarily, the insulation materials **112** may include an insulation material such as an oxide layer.

[0071] A plurality of pillars **113** penetrating the insulation materials along the third direction D3 are sequentially disposed along the second direction D2 on a region of the substrate **111** between the first and second doping regions **311** and **312**. For example, the plurality of pillars **113** penetrate the insulation materials **112** to contact the substrate **111**.

[0072] For example, each pillar **113** may include a plurality of materials. For example, a channel layer **114** of each pillar **113** may include a silicon material having a first type. For example, the channel layer **114** of each pillar **113** may include a silicon material having the same type as the substrate **111**. In an embodiment, the channel layer **114** of each pillar **113** includes a p-type silicon. However, the channel layer **114** of each pillar **113** is not limited to the p-type silicon.

[0073] An internal material **115** of each pillar **113** includes an insulation material. For example, the internal material **115** of each pillar **113** may include an insulation material such as a silicon oxide. For example, the inner material **115** of each pillar **113** may include an air gap.

[0074] An insulation layer **116** is provided along the exposed surfaces of the insulation materials **112**, the pillars **113**, and the substrate **111**, on a region between the first and second doping regions **311** and **312**. Exemplarily, the insulation layer **116** provided on the exposed surface in the third direction D3 of the last insulation material **112** may be removed.

[0075] A plurality of first conductive materials **211** to **291** is provided between second doping regions **311** and **312** on the exposed surfaces of the insulation layer **116**. For example, the first conductive material **211** extending along the second direction D2 is provided between the substrate **111** and the insulation material **112** adjacent to the substrate **111**.

[0076] A first conductive material extending along the first direction D1 is provided between the insulation layer **116** at the top of a specific insulation material among the insulation materials **112** and the insulation layer **116** at the bottom of a specific insulation material among the insulation materials **112**. For example, a plurality of first conductive materials **221** to **281** extending along the first direction D1 are provided between the insulation materials **112** and it may be understood that the insulation layer **116** is provided between the insulation materials **112** and the first conductive materials **221** to **281**. The first conductive materials **211** to **291** may include a metal material. The first conductive materials **211** to **291** may include a conductive material such as a polysilicon.

[0077] The same structures as those on the first and second doping regions **311** and **312** may be provided in a region between the second and third doping regions **312** and **313**. In the region between the second and third doping regions **312** and **313**, provided are a plurality of insulation materials **112** extending along the first direction D1, a plurality of pillars **113** disposed sequentially along the first direction D1 and penetrating the plurality of insulation materials **112** along the third

direction D 3, an insulation layer **116** provided on the exposed surfaces of the plurality of insulation materials **112** and the plurality of pillars **113**, and a plurality of conductive materials **213** to **293** extending along the first direction D1.

[0078] In a region between the third and fourth doping regions **313** and **314**, the same structures as those on the first and second doping regions **311** and **312** may be provided. In the region between the third and fourth doping regions **313** and **314**, provided are a plurality of insulation materials **112** extending along the first direction D1, a plurality of pillars **113** disposed sequentially along the first direction D1 and penetrating the plurality of insulation materials **112** along the third direction D3, an insulation layer **116** provided on the exposed surfaces of the plurality of insulation materials **112** and the plurality of pillars **113**, and a plurality of first conductive materials **213** to **293** extending along the first direction D1.

[0079] Drains **320** are provided on the plurality of pillars **113**, respectively. The drains **320** may include silicon materials doped with a second type. For example, the drains **320** may include silicon materials doped with an n-type. In an embodiment, the drains **320** include n-type silicon materials. However, the drains **320** are not limited to the n-type silicon materials.

[0080] On the drains, the second conductive materials **331** to **333** extending along the first direction D1 are provided. The second conductive materials **331** to **333** are disposed along the second direction D2, being spaced by a specific distance. The second conductive materials **331** to **333** are respectively connected to the drains **320** in a corresponding region. The drains **320** and the second conductive material **333** extending along the first direction D1 may be connected through each contact plug. The second conductive materials **331** to **333** may include metal materials. The second conductive materials **331** to **333** may include conductive materials such as a polysilicon.

[0081] In example embodiments, each of the first conductive materials **211** to **291** may form a word-line or a selection line SSL/GSL. The first conductive materials **221** to **281** may be used as word-lines, and first conductive materials formed at the same layer may be interconnected. The memory block BLKi may be selected when the first conductive materials **211** to **291** all are selected. On the other hand, a sub-block may be selected by selecting a part of the first conductive materials **211** to **291**.

[0082] The number of layers at which first conductive materials **211** to **291** are formed may not be limited to this disclosure. It is well understood that the number of layers at which the first conductive materials **211** to **291** are formed is changed according to a process technique and a control technique.

[0083] In example embodiments, each of the second conductive materials **331** to **333** may form a bit-line and each of the doping regions **311** to **314** may form a common source line of the cell strings.

[0084] FIG. 6 is a circuit diagram illustrating a mat configuration in the nonvolatile memory device of FIG. 3 according to exemplary embodiments.

[0085] Referring to FIG. 6, a memory cell array **100b** including first and second mats MAT1 and MAT2 is illustrated. Each of the first and second mats MAT1 and MAT2 includes a plurality of memory blocks, and each of the memory blocks includes a plurality of cell strings. For example, a memory block of the first mat MAT1 includes a plurality of cell strings CS11, CS12, CS21, and CS22. The plurality of cell strings in a mat may be formed in a plane. Each of the first and second mats MAT1 and MAT2 includes a plurality of memory blocks, and one of the memory blocks has multiple string selection lines SSL1a and SSL1b to select at least one of the cell strings CS11, CS12, CS21, and CS22. For example, when a selection voltage is applied to a first string selection line SSL1a, the first and second cell strings CS11 and CS12 may be selected. When a selection voltage is applied to a second string selection line SSL1b, third and fourth cell strings CS21 and CS22 may be selected.

[0086] In some embodiments, the first and second mats MAT1 and MAT2 may have the same physical structure. For example, like the first mat MAT1, the second mat MAT2 may include

multiple memory blocks and multiple cell strings formed in a memory block of the multiple memory blocks. Also, the second mat MAT2 may include multiple string selection lines SSL2a and SSL2b to select at least one of multiple cell strings.

[0087] Each of the first and second mats MAT1 and MAT2 may be coupled to corresponding word-lines and a common source line. The cell strings in the first mat MAT1 may be coupled to word-lines WL11~WL16, a ground selection line GSL1 and a common source line CSL1. The cell strings in the second mat MAT2 may be coupled to word-lines WL21~WL26, a ground selection line GSL2 and a common source line CSL2.

[0088] The first and second mats MAT1 and MAT2 do not share bit-lines. First bit-lines BL1 and BL1a are coupled to the first mat MAT1 exclusively. Second bit-lines BL2 and BL2a are coupled to the second mat MAT2 exclusively.

[0089] Although FIG. 6 illustrates an example in which each mat is connected with two bit-lines and six word-lines, the inventive concept is not limited to these features. For example, each mat can be connected with three or more bit-lines and seven or more word-lines.

[0090] Each cell string may include at least one string selection transistor, memory cells, and at least one ground selection transistor. For example, a cell string CS31 of the second mat MAT2 may include a ground selection transistor GST, multiple memory cells MC1 to MC6, and a string selection transistor SST sequentially being perpendicular to a substrate. The remaining cell strings may be formed substantially the same as the cell string CS31.

[0091] The first and second mats MAT1 and MAT2 include independent string selection lines. For example, string selection lines SSL1a and SSL1b are only connected with the first mat MAT1, and string selection lines SSL2a and SSL2b are only connected with the second mat MAT2. A string selection line may be used to select cell strings only in a mat. Also, cell strings may be independently selected in every mat by controlling the string selection lines independently.

[0092] For example, cell strings CS11 and CS12 may be independently selected by applying a selection voltage only to first string selection line SSL1a. When the selection voltage is applied to first string selection line SSL1a, string selection transistors of cell strings CS11 and CS12 corresponding to first string selection line SSL1a may be turned on by the selection voltage. In this case, memory cells of the cell strings CS11 and CS12 may be electrically connected with a bit-line. When a non-selection voltage is applied to first string selection line SSL1a, string selection transistors of cell strings CS11 and CS12 corresponding to first string selection line SSL1a are turned off by the non-selection voltage. In this case, memory cells of the cell strings CS11 and CS12 are electrically isolated from a bit-line.

[0093] Referring back to FIG. 3, the control circuit 500 may receive a command (signal) CMD and an address (signal) ADDR from the memory controller 20 and control an erase loop, a program loop and a read operation of the nonvolatile memory device 30 based on the command signal CMD and the address signal ADDR. The program loop may include a program operation and a program verification operation. The erase loop may include an erase operation and an erase verification operation.

[0094] In example embodiments, the control circuit 500 may generate the control signals CTLs, which are used for controlling the voltage generator 700, may generate the first control signal LTC1 for controlling the row decoder 600 and may generate the second control signal LTC2 for controlling the page buffer circuit 410, based on the command signal CMD. The control circuit 500 may generate the row address R_ADDR and the column address C_ADDR based on the address signal ADDR. The control circuit 500 may provide the row address R_ADDR to the row decoder 600 and provide the column address C_ADDR to the data input/output circuit 420. The control circuit 500 may include the decision circuit 520 to determine an operation mode based on a number of mats which operate simultaneously. A concept of plane may be used instead of a concept of the mat.

[0095] The row decoder 600 may be coupled to the memory cell array 100 through the string

selection line SSL, the plurality of word-lines WLs, and the ground selection line GSL. During the program operation or the read operation, the row decoder **600** may determine one of the plurality of word-lines WLs as the selected word-line and determine rest of the plurality of word-lines WLs except for the selected word-line as unselected word-lines based on the row address R_ADDR. [0096] The voltage generator **700** may generate word-line voltages VWLs, which are required for the operation of the memory cell array **100** of the nonvolatile memory device **30**, based on the control signals CTLs. The voltage generator **700** may receive the power PWR from the memory controller **20**. The word-line voltages VWLs may be applied to the plurality of word-lines WLs through the row decoder **600**.

[0097] For example, during the erase operation, the voltage generator **700** may apply an erase voltage to a well of a memory block and may apply a ground voltage to entire word-lines of the memory block. During the erase verification operation, the voltage generator **700** may apply an erase verification voltage to the entire word-lines of the memory block or sequentially apply the erase verification voltage to word-lines in a word-line basis.

[0098] For example, during the program operation, the voltage generator **700** may apply a program voltage to the selected word-line and may apply a program pass voltage to the unselected word-lines. In addition, during the program verification operation, the voltage generator **700** may apply a program verification voltage to the selected word-line and may apply a verification pass voltage to the unselected word-lines.

[0099] In addition, during the read operation, the voltage generator **700** may apply a read voltage to the selected word-line and may apply a read pass voltage to the unselected word-lines.

[0100] The page buffer circuit **410** may be coupled to the memory cell array **100** through the plurality of bit-lines BLs. The page buffer circuit **410** may include a plurality of page buffers. In some exemplary embodiments, one page buffer may be connected to one bit-line. In other exemplary embodiments, one page buffer may be connected to two or more bit-lines.

[0101] The page buffer circuit **410** may temporarily store data to be programmed in a selected page or data read out from the selected page of the memory cell array **100**.

[0102] The data input/output circuit **420** may be coupled to the page buffer circuit **410** through data lines DLs. During the program operation, the data input/output circuit **410** may receive program data DATA from the memory controller **20** and provide the program data DATA to the page buffer circuit **410** based on the column address C_ADDR received from the control circuit **500**. During the read operation, the data input/output circuit **420** may provide read data DATA, which are stored in the page buffer circuit **410**, to the memory controller **20** based on the column address C_ADDR received from the control circuit **500**.

[0103] In addition, the page buffer circuit **410** and the data input/output circuit **420** read data from a first area of the memory cell array **100** and write the read data to a second area of the memory cell array **100**. That is, the page buffer circuit **410** and the data input/output circuit **420** may perform a copy-back operation.

[0104] FIG. 7 is a block diagram illustrating the control circuit in the nonvolatile memory device of FIG. 3 according to exemplary embodiments.

[0105] Referring to FIG. 7, the control circuit **500** includes a command decoder **510**, a decision circuit **520**, an address buffer **530**, a control signal generator **540**, a first level/timing controller **550** and a second level/timing controller **560**.

[0106] The command decoder **510** decodes the command CMD and provides a decoded command D_CMD to the control signal generator **540**. The address buffer **530** receives the address signal ADDR, provides the row address R_ADDR to the row decoder **600** and provides the column address C_ADDR to the data input/output circuit **420**.

[0107] The decision circuit **520** receives the command CMD and generates a mode signal MS designating one of a single mat mode and a multi-mat mode in response to the command CMD. An operation of the nonvolatile memory device is performed on one of the plurality of mats in the

single mat mode, and an operation of the nonvolatile memory device is simultaneously performed on at least two mats of the plurality of mats in the multi-mat mode. The single mat mode may be also referred to as a single plane mode or a single speed mode. The multi-mat mode may be also referred to as a multi-plane mode or a multi-speed mode. The decision circuit **520** provides the mode signal MS to the control signal generator **540**, the first level/timing controller **550** and the second level/timing controller **560**.

[0108] The control signal generator **540** receives the decoded command D_CMD and the mode signal MS, generates the control signals CTLs based on an operation directed by the decoded command D_CMD and an operation mode directed by the mode signal MS and provides the control signals CTLs to the voltage generator **700**.

[0109] The first level/timing controller **550** receives the mode signal MS, generates the first control signal LTC1 based on the mode designated by the mode signal MS, provides the first control signal LTC1 to the row decoder **600**. The first level/timing controller **550** receives setting information on levels of the word-line voltages and application time interval of the word-line voltages for the single mat mode and the multi-mat mode as a command set CMDSET from the memory controller **20** and stores the command set CMDSET therein. The first level/timing controller **550** provides the row decoder **600** with the first control signal LTC1 indicating the setting information of the word-line voltages in response to the mode signal MS.

[0110] The second level/timing controller **560** receives the mode signal MS, generates the second control signal LTC2 based on the mode designated by the mode signal MS, provides the second control signal LTC2 to the page buffer circuit **410**. The second level/timing controller **560** receives setting information on levels of voltages applied to the bit-lines (i.e., bit-line voltages) and application time interval of the bit-line voltages for the single mat mode and the multi-mat mode as the command set CMDSET from the memory controller **20** and stores the command set CMDSET therein. The second level/timing controller **560** provides the page buffer circuit **410** with the second control signal LTC2 indicating the setting information of the bit-line voltages in response to the mode signal MS.

[0111] FIG. **8** is a block diagram illustrating the voltage generator in the nonvolatile memory device of FIG. **3** according to exemplary embodiments.

[0112] Referring to FIG. **8**, the voltage generator **700** may include a high voltage generator **710** and a low voltage generator **730**. The voltage generator **700** may further include a negative voltage generator **750**.

[0113] The high voltage generator **710** may generate a program voltage VPGM, a program pass voltage VPPASS, a verification pass voltage VVPASS, a read pass voltage VRPASS and an erase voltage VERS according to operations directed by the decoded command D_CMD, in response to a first control signal CTL1 of the control signals CTLs.

[0114] Levels of the program voltage VPGM, the program pass voltage VPPASS, the verification pass voltage VVPASS, the read pass voltage VRPASS may be different in the single mat mode and the multi-mat mode. The program voltage VPGM is applied to the selected word-line, the program pass voltage VPPASS, the verification pass voltage VVPASS, the read pass voltage VRPASS may be applied to the unselected word-lines and the erase voltage VERS may be applied to the well of the memory block. The first control signal CTL1 may include a plurality of bits which indicate the operations directed by the decoded command D_CMD and the mode designated by the mode signal MS.

[0115] The low voltage generator **730** may generate a program verification voltage VPV, a read voltage VRD and an erase verification voltage VEV according to operations directed by the decoded command D_CMD, in response to a second control signal CTL2 of the control signals CTLs. Levels of the program verification voltage VPV, the read voltage VRD and the erase verification voltage VEV may be different in the single mat mode and the multi-mat mode. The program verification voltage VPV, the read voltage VRD and the erase verification voltage VEV

may be applied to the selected word-line according to operation of the nonvolatile memory device **30**. The second control signal CTL2 may include a plurality of bits which indicate the operations directed by the decoded command D_CMD and the mode designated by the mode signal MS. [0116] The negative voltage generator **750** may generate a program verification voltage VPV', a read voltage VRD' and an erase verification voltage VEV' which have negative levels according to operations directed by the decoded command D_CMD, in response to a third control signal CTL3 of the control signals CTLs. Levels of the program verification voltage VPV', the read voltage VRD' and the erase verification voltage VEV' may be different in the single mat mode and the multi-mat mode. The third control signal CTL3 may include a plurality of bits which indicate the operations directed by the decoded command D_CMD and the mode designated by the mode signal MS.

[0117] Although not illustrated, the voltage generator **700** may generate other voltages that will be described in FIGS. **15** and **17**.

[0118] FIG. **9** is a block diagram illustrating the row decoder in the nonvolatile memory device of FIG. **3** according to exemplary embodiments.

[0119] In FIG. **9**, the first mat MAT1 and the second mat MAT2 of the memory cell array **100** and the voltage generator **700** are altogether illustrated.

[0120] Referring to FIG. **9**, the row decoder **600** includes a decoder **610**, a first switch circuit **620** and a second switch circuit **630**.

[0121] The decoder **610** receives the address ADDR and the mode signal MS, and generates a first mat selection signal MSS1 to select the first mat MAT1 and a second mat selection signal MSS2 to select the second mat MAT2 based on at least one mat designated by the address ADDR and the mode designated by the mode signal MS. When the mode signal MS indicates the single mat mode, the decoder **610** enables one of the first mat selection signal MSS1 and the second mat selection signal MSS2. When the mode signal MS indicates the multi-mat mode, the decoder **610** enables both the first mat selection signal MSS1 and the second mat selection signal MSS2. The decoder **610** provides the first mat selection signal MSS1 and the second mat selection signal MSS2 to the first mat MAT1 and the second mat MAT2 respectively.

[0122] The first switch circuit **620** and the second switch circuit **630** may be coupled to a plurality of selection lines SIs coupled to the voltage generator **700**. The first switch circuit **620** is coupled to the first mat MAT1 through at least one string selection line SSL, a plurality of word-lines WL1~WLn and at least one ground selection line GSL. The second switch circuit **630** is coupled to the second mat MAT2 through at least one string selection line SSL, a plurality of word-lines WL1~WLn and at least one ground selection line GSL.

[0123] The first switch circuit **620** includes a switch controller **621** and a plurality of pass transistors PT11~PT14 coupled to the string selection line SSL, the word-lines WL1~WLn and the ground selection line GSL of the first mat MAT1. The switch controller **621** may control turn-on and turn-off of the pass transistors PT11~PT14 and turn-on timing of the pass transistors PT11~PT14 in response to the first mat selection signal MSS1 and the first control signal LTC1. For example, the switch controller **621** may control turn-on timing (e.g., a time interval) of the pass transistors PT11~PT14 by selecting a particular time interval from among a plurality of different time intervals in response to the first mat selection signal MSS1 and the first control signal LTC1.

[0124] The second switch circuit **630** includes a switch controller **631** and a plurality of pass transistors PT21~PT24 coupled to the string selection line SSL, the word-lines WL1~WLn and the ground selection line GSL of the second mat MAT2. The switch controller **631** may control turn-on and turn-off of the pass transistors PT21~PT24 and turn-on timing of the pass transistors PT21~PT24 in response to the second mat selection signal MSS2 and the first control signal LTC1. For example, the switch controller **631** may control turn-on timing (e.g., a time interval) of the pass transistors PT21~PT24 by selecting a particular time interval from among a plurality of different time intervals in response to the second mat selection signal MSS2 and the first control signal

LTC1.

[0125] When the mode signal MS indicates the single mat mode and the address ADDR designates the first mat MAT1, the first mat selection signal MSS1 is enabled and the second mat selection signal MSS2 is disabled. The switch controller 621 enables a first switching control signal SCS1 during a first time interval (or, a first period of time) to turn-on the pass transistors PT11~PT14 during the first time in response to the first control signal LTC1. Therefore, the word-line voltages VWLs having first levels are applied to the first mat MAT1.

[0126] When the mode signal MS indicates a first sub mode of the multi-mat mode, the first and second mat selection signals MSS1 and MSS2 are enabled. The switch controller 621 enables a first switching control signal SCS1 during a first time interval to turn-on the pass transistors PT11~PT14 during the first time interval in response to the first control signal LTC1 and the switch controller 631 enables a second switching control signal SCS2 during the first time interval to turn-on the pass transistors PT21~PT24 during the first time interval in response to the first control signal LTC1. In example embodiments, voltage generator 700 may generate the word-line voltages VWLs in response to the control signals CTLs. In other example embodiments, the voltage generator 700 may generate the word-line voltages VWLs in response to the control signals CTLs and the first control signal LTC1. In this case, the voltage generator 700 may generate the word-line voltages VWLs by selecting one of different voltages in response to the control signals CTLs and the first control signal LTC1. For example, the word-line voltages VWLs having second levels greater than the first levels are applied to the first mat MAT1 and the second mat MAT2.

[0127] When the mode signal MS indicates a second sub mode of the multi-mat mode, the first and second mat selection signals MSS1 and MSS2 are enabled. The switch controller 621 enables a first switching control signal SCS1 during a second time interval longer than the first time interval to turn-on the pass transistors PT11~PT14 during the second time interval in response to the first control signal LTC1 and the switch controller 631 enables a second switching control signal SCS2 during the second time interval to turn-on the pass transistors PT21~PT24 during the second time interval in response to the first control signal LTC1. For example, the word-line voltages VWLs having the first levels are applied to the first mat MAT1 and the second mat MAT2.

[0128] In example embodiments, each of the first mat MAT1 and the second mat MAT2 may have an associated row decoder for applying word-line voltages to the word-lines. Thus, each of the first mat MAT1 and the second mat MAT2 can be operated separately from each other or simultaneously together based on the mode signal MS, the control signals CTLs, the first control signal LTC1, and the second control signal LTC2.

[0129] The word-line voltages VWLs may be transferred to the plurality of word-lines WLs and at least one of the string selection line SSL through the plurality of signal lines Sls.

[0130] FIGS. 10 and 11 illustrate the word-line voltages or the bit-line voltages in the single mat mode and the multi-mat mode respectively, according to exemplary embodiments.

[0131] In FIG. 10, a reference numeral 641 represents one of the word-line voltages or one of the bit-line voltages in the single mat mode and a reference numeral 642 represents one of the word-line voltages or one of the bit-line voltages in the multi-mat mode. The level of the word-line voltage or the bit-line voltage in the multi-mat mode is higher than the level of the word-line voltage or the bit-line voltage in the single mat mode after a reference numeral 643. The reference numeral 643 may indicate that sensing timing is same for the single mat mode and the multi-mat mode.

[0132] Although not illustrated, the level of the word-line voltage or the bit-line voltage in the multi-mat mode may be lower than the level of the word-line voltage or the bit-line voltage in the single mat mode.

[0133] In FIG. 11, a reference numeral 651 represents one of the word-line voltages or one of the bit-line voltages in the single mat mode and a reference numeral 652 represents one of the word-line voltages or one of the bit-line voltages in the multi-mat mode. Application time interval of the

word-line voltage or the bit-line voltage in the multi-mat mode may be longer than the application time interval of the word-line voltage or the bit-line voltage in the single mat mode. In this case, the applied voltage (word-line voltage or bit-line voltage) is the same in the single mat mode and the multi-mat mode. A reference numeral **653** may indicate that sensing time for the single mat mode and a reference numeral **654** for the multi-mat mode. The reference numerals **653** and **654** indicate that sensing timings are different for the single mat mode and the multi-mat mode. Although not illustrated, the application time interval of the word-line voltage or the bit-line voltage in the multi-mat mode may be shorter than the application time interval of the word-line voltage or the bit-line voltage in the single mat mode.

[0134] Although a voltage level of the word-line voltage may be different from a voltage level of the bit-line voltage, a difference between the voltage levels of the word-line voltage and the bit-line voltage is not shown in FIGS. **10** and **11** for convenience in explanation.

[0135] FIG. **12** illustrates the nonvolatile memory device of FIG. **3** according to exemplary embodiments.

[0136] In FIG. **12**, the first mat MAT**1** of the memory cell array **100** includes a first memory cell MC**1** coupled to a word-line WL**1** and a bit-line BL**1** and the second mat MAT**2** of the memory cell array **100** includes a second memory cell MC**2** coupled to the word-line WL**1** and a bit-line BL**2**. The first memory cell MC**1** is coupled to a selection line S**1** through a pass transistor PT**1** receiving the first switching control signal SCS**1** and the second memory cell MC**2** is coupled to the selection line S**1** through a pass transistor PT**2** receiving the second switching control signal SCS**2**.

[0137] The bit-line BL**1** is coupled to a page buffer PB**1**, the bit-line BL**2** is coupled to a page buffer PB**2** and the second level/timing controller **560** generates the second control signal LTC**2** and controls the page buffers PB**1** and PB**2** in response to the second control signal LTC**2**.

[0138] In example embodiments, a bit-line voltage generator (not shown) may generate variable bit-line voltages in response to the second control signal LTC**2**. For example, the bit-line voltage generator (not shown) may generate a selected bit-line voltage by selecting one of different voltages in response to the second control signal LTC**2**. The bit-line voltage generator (not shown) may be connected to the page buffers PB**1** and PB**2** and may apply the bit-line voltages to the page buffers PB**1** and PB**2**. The page buffers PB**1** and PB**2** may apply bit-line voltages to the bit-lines BL**1** and BL**2**.

[0139] In example embodiments, the bit-line voltage generator (not shown) may be included in each of the page buffers PB**1** and PB**2**, or disposed separately from the page buffers PB**1** and PB**2**.

[0140] In example embodiments, each of the page buffers PB**1** and PB**2** may apply a bit-line voltage to the selected bit-line during a selected time interval from among a plurality of different time intervals in response to the mode signal MS and the second control signal LTC**2**.

[0141] In example embodiments, each of the first mat MAT**1** and the second mat MAT**2** may have an associated page buffer for applying bit-line voltages to the bit-lines. Thus, each of the first mat MAT**1** and the second mat MAT**2** can be operated separately from each other or simultaneously together based on the mode signal MS and the second control signal LTC**2**.

[0142] FIG. **13** is a timing diagram illustrating the word-line voltages and the bit-line voltages applied to the first and second mats in the single mat mode and the multi-mat mode in FIG. **6** when a read operation is performed on the nonvolatile memory device of FIG. **3**, according to exemplary embodiments.

[0143] Referring to FIGS. **3** through **13**, when the read operation is performed on the nonvolatile memory device **30**, a selection voltage VSSL is applied to a selected string selection line SEL_SSL during first through fifth intervals P**11**~P**15**, a first pre-pulse PREP**1** is applied to an unselected string selection line UNSEL_SSL during the first interval P**11**, the unselected string selection line UNSEL_SSL is discharged with a ground voltage during the second through fourth intervals P**12**~P**14** and a first post-pulse PSTP**1** is applied to the unselected string selection line UNSEL_SSL during the fifth interval P**15**.

[0144] In addition, a second pre-pulse PREP2 is applied to a selected word-line SEL WL during the first interval P11, the read voltage VR is applied to the selected word-line SEL WL during the second through fourth intervals P12~P14 and a second post-pulse PSTP2 is applied to the selected word-line SEL_WL during the fifth interval P15. A read pass voltage VRPASS is applied to an unselected word-line UNSEL_WL during the first through fifth intervals P11~P15.

[0145] The bit-line BL is set-up during the first interval P11, is precharged by receiving a precharge voltage VPCH during the second interval P12, is developed during the third interval P13, is clamped with a voltage VCMP during the third and fourth intervals P13 and P14, and is discharged with the ground voltage during the fifth interval P15.

[0146] FIG. 14 illustrates that one of the word-line voltages or one of the bit-line voltages in the single mat mode is over-driven in the multi-mat mode, according to exemplary embodiments.

[0147] In FIG. 14, a reference numeral 660 represents one of the word-line voltages or one of the bit-line voltages in the single mat mode and a reference numeral 670 represents one of the word-line voltages or one of the bit-line voltages in the multi-mat mode. The voltage level is over-driven by an amount OD and then reduced to the voltage level of the single mat mode in the multi-mat mode. Over-driving the voltage levels may mean that the voltage levels are different in the single mat mode and the multi-mat mode and over-driving the voltage levels may be applicable to overall program operation in addition to the read operation.

[0148] FIG. 15 is a table illustrating setting values of levels and application time interval of the word-line voltages and the bit-line voltages applied to the first second mats in FIGS. 13 and 14 when a read operation is performed on the nonvolatile memory device of FIG. 3, according to exemplary embodiments.

[0149] Referring to FIG. 15, when the read operation is performed on the nonvolatile memory device 30, it is noted that the setting values of levels and application time interval of the word-line voltages and the bit-line voltages in the single mat mode are smaller than the setting values of levels and application time interval of the word-line voltages and the bit-line voltages in the multi-mat mode.

[0150] The setting values in FIG. 15 may be stored as the command set CMDSET in the first level/timing controller 550 and the second level/timing controller 560 in FIG. 7. In addition, the setting values in FIG. 15 may be stored based on information which is predetermined in the nonvolatile memory device 30. The first level/timing controller 550 and the second level/timing controller 560 may control the row decoder 600 and the page buffer circuit 410 respectively by referring the setting values such that at least one of the voltage levels and the application time interval are different in the single mat mode and the multi-mat mode.

[0151] For example, a level of the second pre-pulse PREP2 applied to a selected word-line SEL_WL may be 5.3V in the single mat mode and may be 5.5V in the multi-mat mode, during a specific period of time (e.g., the first interval P11). As another example, the second pre-pulse PREP2 having a particular voltage (e.g., 5.3V) may be applied during 8 us in the single mat mode and may be applied during 8.2 us in the multi-mat mode.

[0152] Although not illustrated, in exemplary embodiments, that the setting values of levels and application time interval of the word-line voltages and the bit-line voltages in the single mat mode are greater than the setting values of levels and application time interval of the word-line voltages and the bit-line voltages in the multi-mat mode.

[0153] FIG. 16 is a timing diagram illustrating the word-line voltages and the bit-line voltages applied to the first and second mats in the single mat mode and the multi-mat mode in FIG. 6 when a program operation is performed on the nonvolatile memory device of FIG. 3, according to exemplary embodiments.

[0154] Referring to FIGS. 3 through 12 and 16, when the program operation is performed on the nonvolatile memory device 30, a word-line set-up voltage VWSTP is applied to a selected word-line SEL_WL during a first interval P21, a program pass voltage VPPASS1 and a program voltage

VPGM are sequentially applied to the selected word-line SEL_WL during a second interval P22 and a program verification voltage VPV is applied to the selected word-line SEL_WL during a third interval P23 to verify whether the program operation is properly performed.

[0155] A ground voltage GND is applied to an unselected word-line UNSEL_WL during the first interval P21 to discharge the unselected word-line UNSEL_WL, a program pass voltage VPPASS2 is applied to the unselected word-line UNSEL_WL during the second interval P22 and a verification pass voltage VVPASS is applied to the unselected word-line UNSEL_WL during the second interval P23.

[0156] The bit-line BL is set-up by receiving the bit-line set-up voltage VBSTP during the first and intervals P21 and P22, is precharged by receiving a precharge voltage VPCCH during the third interval P23, and is discharged after the third interval P23.

[0157] FIG. 17 is a table illustrating setting values of levels and application time interval of the word-line voltages and the bit-line voltages applied to the first and second mats in FIG. 16 when the program operation is performed on the nonvolatile memory device of FIG. 3, according to exemplary embodiments.

[0158] Referring to FIG. 17, when the program operation is performed on the nonvolatile memory device 30, it is noted that the setting values of levels and application time interval of the word-line voltages and the bit-line voltages in the single mat mode are smaller than the setting values of levels and application time interval of the word-line voltages and the bit-line voltages in the multi-mat mode.

[0159] The setting values in FIG. 17 may be stored as the command set CMDSET in the first level/timing controller 550 and the second level/timing controller 560 in FIG. 7. The first level/timing controller 550 and the second level/timing controller 560 may control the row decoder 600 and the page buffer circuit 410 respectively by referring the setting values such that at least one of the voltage levels and the application time interval are different in the single mat mode and the multi-mat mode.

[0160] FIG. 15 illustrates the setting values of levels and application time interval of the word-line voltages and the bit-line voltages in the single mat mode and the multi-mat mode during the read operation on the nonvolatile memory device 30 and FIG. 17 illustrates the setting values of levels and application time interval of the word-line voltages and the bit-line voltages in the single mat mode and the multi-mat mode during the program operation on the nonvolatile memory device 30.

[0161] Although not illustrated, levels and application time interval of the erase voltage applied to the well of the memory block in the erase operation and levels and application time interval of the erase verification voltage in the erase verification operation may be different in the single mat mode and the multi-mat mode. Setting values of the erase voltage and the erase verification voltage may be stored as the command set CMDSET in the first level/timing controller 550 and the second level/timing controller 560.

[0162] The operation on the nonvolatile memory device 30 may include one of the program operation, the read operation and the erase operation.

[0163] FIG. 18 is a block diagram illustrating a memory system according to exemplary embodiments.

[0164] Referring to FIG. 18, a memory system (or a nonvolatile memory system) 15 may include a memory controller 25 and at least one nonvolatile memory device 35.

[0165] The memory system 15 of FIG. 18 differs from the memory system of FIG. 1. The nonvolatile memory device 30 includes the decision circuit 520 in FIG. 1 while the memory controller 25 includes a decision circuit 27.

[0166] When the memory controller 25 includes the decision circuit 27, a control circuit such as the control circuit 500 of FIG. 7, which may be included in the nonvolatile memory device 35, may include components of the control circuit 500 except the decision circuit 520.

[0167] The decision circuit 27 determines a number of mats of the mats MAT1 and MAT2, which

operate simultaneously, and transmits the command CMD or the control signal CTRL including a mode signal indicating the number of mats which operate simultaneously to the nonvolatile memory device **35**.

[0168] For example, when the decision circuit **27** determines a single mat mode or a multi-mat mode of the mats MAT1 and MAT2, the decision circuit **27** may transmit, to the nonvolatile memory device **35**, levels and an application time interval of the word-line voltages or levels and an application time interval of the bit-line voltages applied to the bit-lines as a command set before the decision circuit transmit **25**, to the nonvolatile memory device **35**, a command sequence designating one of the single mat mode and the multi-mat mode.

[0169] For example, when the decision circuit **27** determines the single mat mode or the multi-mat mode of the mats MAT1 and MAT2, the decision circuit **27** may transmit, to the nonvolatile memory device **35**, the levels and an application time interval of the word-line voltages or the levels and an application time interval of voltages of the bit-lines as a command set with the mode signal designating one of the single mat mode and the multi-mat mode. The command set of the setting values may be included in the command sequence transmitted to the nonvolatile memory device **35**.

[0170] FIG. **19** is a flow chart illustrating a method of nonvolatile memory device according to exemplary embodiments.

[0171] Referring to FIG. **1** through **19**, in a method of operating a nonvolatile memory device **30** including a memory cell array including a plurality of mats corresponding to different bit-lines, the nonvolatile memory device **30** receives a command CMD and an address ADDR from a memory controller **20** (**S810**).

[0172] A decision circuit **520** of a control circuit **500** determines an operation mode to one of a single mat mode and a multi-mat mode in response to the command CMD (**S820**).

[0173] The decision circuit **520** provides first and second level/timing controllers **550** and **560** with a mode signal MS designating one of the single mat mode and the multi-mat mode to control the row decoder **600** and the page buffer circuit **410** such that at least one of levels of the word-line voltages or the bit-line voltages and an application time interval of the word-line voltages or the bit-line voltages are different in the single mat mode and the multi-mat mode (**S830**).

[0174] In a nonvolatile memory device, a memory system and a method of a nonvolatile memory device according to exemplary embodiments, levels or application time intervals of the voltages applied to the memory cell array are differentiated in the single mat mode and the multi-mat mode, and performance in both the single mat mode and the multi-mat mode may be enhanced.

[0175] FIG. **20** is a block diagram illustrating a solid state disk or solid state drive (SSD) according to exemplary embodiments.

[0176] Referring to FIG. **20**, an SSD **800** includes multiple nonvolatile memory devices **810** and an SSD controller **900**.

[0177] The nonvolatile memory devices **810** may be optionally supplied with an external high voltage VPP. Each of the nonvolatile memory devices **810** may employ the nonvolatile memory device **30** of FIG. **3**. Each of the nonvolatile memory devices **810** may differentiate levels or application time intervals of the voltages applied to the word-lines and bit-lines of the memory cell array in the single mat mode and in the multi-mat mode

[0178] The SSD controller **900** is connected to the nonvolatile memory devices **810** through multiple channels CH1 to CHi. The SSD controller **900** includes one or more processors **910**, a buffer memory **920**, an ECC block **930**, a host interface **950**, and a nonvolatile memory interface **960**. The buffer memory **920** stores data used to drive the SSD controller **900**.

[0179] The buffer memory **920** includes multiple memory lines each storing data or a command.

[0180] The ECC block **930** calculates error correction code values of data to be programmed at a writing operation and corrects an error of read data using an error correction code value at a read operation.

[0181] FIG. 21 is a block diagram of a memory device according to some embodiments.

[0182] Referring to FIG. 21, a memory device **40** may include a memory cell array **1100** and a peripheral circuit **1200**. The peripheral circuit **1200** may include a pass transistor circuit **1210**, a row decoder **1220**, a control circuit **1230**, and a page buffer circuit **1240**. Although not shown the peripheral circuit **1200** may further include a data I/O circuit, a voltage generator, an I/O interface, column logic, a pre-decoder, a temperature sensor, a command decoder, and/or an address decoder. In some embodiments, the memory device **40** may be a nonvolatile memory device. Hereinafter, the term “memory device” refers to a nonvolatile memory device. The memory cell array **1100** may include a first mat MAT1 and a second mat MAT2. The memory cell array **1100** may include the memory cell array **100b** of FIG. 6.

[0183] In some example embodiments, the memory cell array **1100** and at least a portion of the pass transistor circuit **1210** may be in an upper or first semiconductor layer (e.g., **1300** in FIG. 22), and the row decoder **1220**, the control circuit **1230**, and the page buffer circuit **1240** may be located in a lower or second semiconductor layer (e.g., **1400** in FIG. 22). However, the invention is not limited to these embodiments described above. In some embodiments, at least some of the circuits forming the row decoder **1220** may be in an upper semiconductor layer together with the memory cell array **1100** and the pass transistor circuit **1210**, and the others of the circuits forming the pass transistor circuit **1210**, the control circuit **1230**, and page buffer circuit **1240** may be in a lower semiconductor layer.

[0184] In some example embodiments, the pass transistor circuit **1210** may include a plurality of vertical pass transistors (e.g., TR1, TR3, TRs1, and TRs2 in FIG. 25). For example, a plurality of vertical pass transistors may be on the upper semiconductor layer. In this specification, the term “vertical pass transistor” refers to a transistor including a vertical channel.

[0185] In some example embodiments, the pass transistor circuit **1210** may include at least one normal pass transistor (e.g., TRg in FIG. 27A). In this specification, the term “normal pass transistor” refers to a transistor including a horizontal channel. For example, a plurality of vertical pass transistors may be on an upper semiconductor layer, and a plurality of normal pass transistors may be on a lower semiconductor layer. However, embodiments are not limited thereto, and at least one normal pass transistor may be on the upper semiconductor layer.

[0186] The memory cell array **1100** may be connected to the page buffer circuit **1240** through bit-lines BLs and to the pass transistor circuit **1210** through word-lines WLs, string selection lines SSL, and ground selection lines GSL. In addition, the pass transistor circuit **1210** may be connected to the row decoder **1220** through mat selection signal lines MSS, string selection line driving signal lines SS, word-line driving signal lines SI, and ground selection line driving signal lines GS. The string selection line driving signal lines SS, the word-line driving signal lines SI, and the ground selection line driving signal lines GS may be referred to as “driving signal lines”.

[0187] The memory cell array **1100** may include the first mat MAT1 and the second mat MAT2, and each of the first mat MAT1 and the second mat MAT2 may include a plurality of memory cells. For example, the memory cells may include flash memory cells. Hereinafter, embodiments will be described using, as an example, the case that a plurality of memory cells are NAND flash memory cells. However, embodiments are not limited thereto. In some example embodiments, the plurality of memory cells may be resistive memory cells such as resistive random access memory (ReRAM) cells, phase-change RAM (PRAM) cells, or magnetic RAM (MRAM) cells.

[0188] In some example embodiments, the memory cell array **1100** may include a three-dimensional (3D) memory cell array. The 3D memory cell array may include a plurality of NAND strings, of which each may include memory cells respectively connected to word-lines vertically stacked on a substrate. This was described in detail with reference to FIGS. 4 and 5. However, embodiments are not limited thereto. In some example embodiments, the memory cell array **100** may include a two-dimensional (2D) memory cell array that may include a plurality of NAND strings in rows and columns.

[0189] The control circuit **1230** may generate various control signals for programming data to the memory cell array **1100**, reading data from the memory cell array **1100**, or erasing data from the memory cell array **1100** based on a command CMD, an address ADDR, and a control signal CTRL. For example, the control circuit **1230** may output a row address R_ADDR that is sent to the row decoder **1220** and/or a column address C_ADDR that is sent to the page buffer circuit **1240**. In addition, the control circuit **1230** may generate a first control signal LTC1 for controlling the row decoder **1220** and may generate a second control signal LTC2 for controlling the page buffer circuit **1240**. Accordingly, the control circuit **1230** may generally control various operations of the memory device **40**.

[0190] The control circuit **1230** may employ the control circuit **500** of FIG. 7.

[0191] The row decoder **1220** may output a mat selection signal for selecting one of a plurality of memory blocks of one or both of the first and second mats MAT1 and MAT2 to the mat selection signal lines MSS in response to the row address R_ADDR. In response to the row address R_ADDR, the row decoder **1220** may also output a word-line driving signal for selecting one of the word-lines WL of the selected mat to the word-line driving signal lines SI, a string selection line driving signal for selecting one of the string selection lines SSL to the string selection line driving signal lines SS, and a ground selection line driving signal for selecting one of the ground selection lines GSL to the ground selection line driving signal lines GS. The page buffer circuit **1240** may select some of the bit-lines BL in response to the column address C_ADDR and the second control signal LTC2. The page buffer circuit **1240** may operate as a write driver or a sense amplifier according to an operating mode. The page buffer circuit **1240** may be connected to the data I/O circuit (not shown) and the data I/O circuit may receive or transmit data from or to outside the memory device **40**.

[0192] As the level of memory cells arranged in the memory cell array **1100** (i.e., the number of word-lines WLs stacked in the vertical direction) increases with the development of semiconductor processes, the number of pass transistors driving the word-lines WLs increases, and accordingly, the area of the pass transistor circuit **1210** may increase. At least a portion of the pass transistor circuit **1210** of the memory device **40** may be in a stair area (e.g., stair area SA in FIG. 22) of the word-lines WLs. In some example embodiments, the pass transistor circuit **1210** may include a plurality of vertical pass transistors in the stair area of the word-lines WLs. Accordingly, the area of the pass transistor circuit **1210** overlaps the stair area of the word-lines WLs, and therefore, an increase in a chip size of the memory device **40** may be prevented even when the number of pass transistors increases with the increase in the number of stacked layers of the word-lines WLs. For example, the overall chip size is reduced by using the overlapping stair area SA.

[0193] FIG. 22 is a diagram schematically illustrating the structure of the memory device of FIG. 21 according to some example embodiments.

[0194] Referring to FIGS. 21 and 22, the memory device **40** may include a first semiconductor layer **1300** and a second semiconductor layer **1400**. The first semiconductor layer **1300** may be stacked on the top of the second semiconductor layer **1400** in a vertical direction VD. For example, the second semiconductor layer **1400** may be on the bottom of the first semiconductor layer **1300** in the vertical direction VD.

[0195] In some example embodiments, the memory cell array **1100** and at least some pass transistors of the pass transistor circuit **1210** may be formed in the first semiconductor layer **1300**, and the row decoder **1220**, the control circuit **1230**, and the page buffer circuit **1240** may be formed in the second semiconductor layer **1400**. However, embodiments are not limited thereto, and at least a portion of the circuit of the row decoder **1220** may be in the first semiconductor layer **1300**. Accordingly, the memory device **40** may have a cell over periphery (COP) structure, in which the memory cell array **1100** is above a portion of the periphery circuit **1200** that includes the row decoder **1220**, the control circuit **1230** and/or the page buffer circuit **1240**. The COP structure may effectively reduce a horizontal area and may increase the integration density of the memory device

40.

[0196] In some example embodiments, the first semiconductor layer **1300** and the second semiconductor layer **1400** may be formed in different wafers, respectively, and may be combined with each other using Cu-to-Cu (C2C) wafer bonding, thereby manufacturing the memory device **40**. For example, a plurality of bonding pads may be formed on a first surface of the first semiconductor layer **1300**, and a plurality of bonding pads may be formed on a first surface of the second semiconductor layer **1400**. The bonding pads of the first semiconductor layer **1300** may be connected to the bonding pads of the second semiconductor layer **1400**. However, the memory device **40** is not limited thereto, and the first semiconductor layer **1300** and the second semiconductor layer **1400** may be formed in one wafer.

[0197] In the first semiconductor layer **1300**, the word-lines WL may extend in a first horizontal direction HD1 and the bit-lines BL may extend in a second horizontal direction HD2. The first and second horizontal directions HD1 and HD2 may be perpendicular to one another. Respective ends of the word-lines WL may form a stair shape. In this specification, an area that includes the word-lines WL in a stair shape in the first semiconductor layer **1300** will be referred to as a “stair area SA”.

[0198] In the first semiconductor layer **1300**, a vertical channel structure may be formed, thereby forming a cell area CA in which memory cells are formed. Accordingly, the memory cell array **1100** may be located in the cell area CA.

[0199] FIG. **23** is a diagram illustrating a row decoder and a pass transistor circuit in the memory device of FIG. **21** according to an example embodiment.

[0200] Referring to FIG. **23**, the first mat MAT1 and the second mat MAT2 are illustrated. The row decoder **1220a** may be an example of the row decoder **1220** in FIG. **21**, and a pass transistor circuit **1210a** and a pass transistor circuit **1210b** may be an example of the pass transistor circuit **1210** in FIG. **21**.

[0201] The row decoder **1220a** may include a mat decoder **1221a** and a driving signal line decoder **1222a**. Each of the pass transistor circuits **1210a** and **1210b** may include a plurality of pass transistors, e.g., a pass transistor TRs, first through n-th pass transistors TR1 through TRn, and a pass transistor TRg, where “n” may be a positive integer. The pass transistor circuit **1210a** may be provided for each of mats, and the mat decoder **1221a** and the driving signal line decoder **1222a** may be provided in common for the mats.

[0202] The mat decoder **1221a** may be connected to the pass transistor circuit **1210a** through a mat selection signal line MS1. For example, the mat selection signal line MS1 may be connected to respective gates of the pass transistors, e.g., the pass transistor TRs, the first through n-th pass transistors TR1 through TRn, and the pass transistor TRg in the pass transistor circuit **1210a**. The mat decoder **1221a** may be connected to the pass transistor circuit **1210b** through a mat selection signal line MS2. For example, the mat selection signal line MS2 may be connected to respective gates of the pass transistors, e.g., the pass transistor TRs, the first through n-th pass transistors TR1 through TRn, and the pass transistor TRg in the pass transistor circuit **1210b**. When a mat selection signal provided through the mat selection signal line MS1 or the mat selection signal line MS2 is activated, or two mat selection signals provided through the mat selection signal line MS1 and the mat selection signal line MS2 are activated, the pass transistors, e.g., the pass transistor TRs, the first through n-th pass transistors TR1 through TRn, and the pass transistor TRg, are turned on, and accordingly, one or two of the mats MAT1 and MAT2 may be selected. For example, in a single mat mode, one of the mats MAT1 and MAT2 may be selected, and in a multi-mat mode, both of the mats MAT1 and MAT2 may be selected in response to mat selection signals.

[0203] The driving signal line decoder **1222a** may be connected to the pass transistor circuits **1210a** and **1210b** through a string selection line driving signal line SS, first through n-th word line driving signal lines S11 through S1n, and a ground selection line driving signal line GS. For example, the string selection line driving signal line SS, the first through n-th word line driving

signal lines SI1 through SIn, and the ground selection line driving signal line GS may be respectively connected to respective sources of the pass transistors, e.g., the pass transistor TRs, the first through n-th pass transistors TR1 through TRn, and the pass transistor TRg. For example, the first word line driving signal line SI1 may be connected to the first pass transistor TR1, the second word line driving signal line SI2 may be connected to the second pass transistor TR2, and the n-th word line driving signal line SIn may be connected to the n-th pass transistor TRn of the pass transistor circuits **1210a** and **1210b**.

[0204] Each of the pass transistor circuits **1210a** and **1210b** may be connected to first and second mats MAT1 and MAT2 through a ground selection line GSL, first through n-th word lines WL1 through WLn, and a string selection line SSLu. The first through n-th pass transistors TR1 through TRn may respectively connect the first through n-th word lines WL1 through WLn to the first through n-th word line driving signal lines SI1 through SIn. For example, the first pass transistor TR1 may be connected to the first word line WL1 and may connect the first word line WL1 to the first word line driving signal line SI1. The second pass transistor TR2 may be connected to the second word line WL2 and may connect the second word line WL2 to the second word line driving signal line SI2. The n-th pass transistor TRn may be connected to the n-th word line WLn and may connect the n-th word line WLn to the n-th word line driving signal line SIn.

[0205] The pass transistor TRs may connect the string selection line SSLu to the string selection line driving signal line SS corresponding to the string selection line SSLu. The pass transistor TRg may connect the ground selection line GSL to the ground selection line driving signal line GS corresponding to the ground selection line GSL. For example, when a mat selection signal is activated, the pass transistor TRs, the first through n-th pass transistors TR1 through TRn, and the pass transistor TRg may respectively provide driving signals, which are respectively provided through the string selection line driving signal line SS, the first through n-th word line driving signal lines SI1 through SIn, and the ground selection line driving signal line GS, to the string selection line SSLu, the first through n-th word lines WL1 through WLn, and the ground selection line GSL.

[0206] In some example embodiments, the pass transistor TRs and the first through n-th pass transistors TR1 through TRn may be implemented as vertical pass transistors. In this specification, the term “vertical pass transistor” refers to a transistor including a vertical channel. For example, the pass transistor TRs and the first through n-th pass transistors TR1 through TRn may be in a stair area (e.g., SA in FIG. 22) of word lines. In some example embodiments, the pass transistor TRg may be implemented as a normal pass transistor. For example, the pass transistor TRg may be in a second semiconductor layer (e.g., **1400** in FIG. 22). This will be described with reference to the drawings including FIG. 27A.

[0207] FIG. 24 is a diagram of the memory device including the pass transistor circuit in FIG. 23, according to some example embodiments. FIG. 25 is a cross-sectional view taken along a line A-A' of FIG. 24, according to some example embodiments. FIG. 26 is a cross-sectional view taken along a line B-B' of FIG. 24, according to some example embodiments. In detail, FIG. 24 is a diagram of the first semiconductor layer of the memory device of FIG. 22, which is viewed from below in the vertical direction VD.

[0208] Referring to FIGS. 24 and 25, the first semiconductor layer **1300** of the memory device **40** may include a plurality of word lines, e.g., the first through n-th word lines WL1 through WLn. The first through n-th word lines WL1 through WLn may be sequentially stacked in the vertical direction VD and may extend in the first horizontal direction HD1. Although not shown, the first through n-th word lines WL1 through WLn may be electrically insulated by a plurality of insulating layers. Respective ends of the first through n-th word lines WL1 through WLn in the first horizontal direction HD1 may be implemented in a stair shape in the stair area SA.

[0209] Each of the first through n-th word lines WL1 through WLn may include a conductive region W and an insulating region NT contact to each other in the stair area SA. For example, each

of the first through n-th word lines WL1 through WLn may include the conductive region W, which is in contact with a contact CP corresponding to each word line, and the insulating region NT, which is in contact with a contact CP not corresponding thereto (e.g., a contact CP connected to another word line).

[0210] Here, the conductive region W may include a conductive material such as tungsten but is not limited to tungsten. The insulating region NT may include an insulating material such as nitride but is not limited to nitride.

[0211] The first word line WL1 may be below a gate GT, and the second through n-th word lines WL2 through WLn may be sequentially formed below the first word line WL1 in the vertical direction VD.

[0212] Each of the first through n-th word lines WL1 through WLn may be connected to a vertical channel VC corresponding thereto through the contact CP corresponding thereto. For example, the vertical channel VC corresponding to the first word line WL1 may be connected to the first word line driving signal line SI1, the vertical channel VC corresponding to the second word line WL2 may be connected to the second word line driving signal line SI2, the vertical channel VC corresponding to the third word line WL3 may be connected to the third word line driving signal line SI3, and the vertical channel VC corresponding to the fourth word line WL4 may be connected to the fourth word line driving signal line SI4. The first through n-th word lines WL1 through WLn may extend in the first horizontal direction HD1, and a word line at one level may be divided by a word line cut region WLC.

[0213] The first semiconductor layer 1300 of the memory device 40 may include the ground selection line GSL disposed above the first through n-th word lines WL1 through WLn and the common source line CSL disposed above the ground selection line GSL. In some example embodiments, a plurality of driving signal lines, e.g., the first through fourth word line driving signal lines SI1 through SI4 and first through fourth string selection line driving signal lines SS1 through SS4, and the common source line CSL may be arranged in the same level (i.e., the same layer). For example, a plurality of driving signal lines, e.g., the first through fourth word line driving signal lines SI1 through SI4 and first through fourth string selection line driving signal lines SS1 through SS4, and the common source line CSL may be formed by the same process. In some example embodiments, a plurality of driving signal lines, e.g., the first through fourth word line driving signal lines SI1 through SI4 and the first through fourth string selection line driving signal lines SS1 through SS4, may extend in the second horizontal direction HD2 and may be apart from one another in the first horizontal direction HD1. In some example embodiments, the common source line CSL may extend in the second horizontal direction HD2 and may be implemented by a metal plate. Although only the first through fourth word line driving signal lines SI1 through SI4 are illustrated in FIGS. 24 and 25 for convenience of description, the first through n-th word line driving signal lines SI1 through SIn may be included in the memory device 40 to respectively correspond to the first through n-th word lines WL1 through WLn, thereby respectively providing corresponding word line driving signals to the first through n-th word lines WL1 through WLn.

[0214] The first semiconductor layer 1300 of the memory device 40 may further include string selection lines SSLu below the first through n-th word lines WL1 through WLn. For example, the string selection lines SSLu may include first through fourth string selection lines SSLu1 through SSLu4. The first through fourth string selection lines SSLu1 through SSLu4 may be arranged in the same level and may be separated from each other by a string selection line cut region SSLC. Each of the first through fourth string selection lines SSLu1 through SSLu4 may be connected to the vertical channel VC corresponding thereto through the contact CP corresponding thereto. The vertical channel VC corresponding to the first string selection line SSLu1 may be connected to the first string selection line driving signal line SS1, the vertical channel VC corresponding to the second string selection line SSLu2 may be connected to the second string selection line driving signal line SS2, the vertical channel VC corresponding to the third string selection line SSLu3 may

be connected to the third string selection line driving signal line SS3, and the vertical channel VC corresponding to the fourth string selection line SSLu4 may be connected to the fourth string selection line driving signal line SS4.

[0215] Although it is illustrated in FIG. 25 that the memory device 40 includes the string selection line SSLu of one layer, embodiments are not limited thereto. In some example embodiments, the memory device 40 may include two string selection lines (e.g., SSLu and SSLd in FIG. 27A) stacked in the vertical direction VD.

[0216] In some example embodiments, the ground selection line GSL, the string selection line SSLu, and the gate GT may include the same material as the first through n-th word lines WL1 through WLn. For example, the ground selection line GSL, the string selection line SSLu, and the gate GT may include the same material as the conductive region W.

[0217] A plurality of vertical channel structures VP may be in the channel area CA of the first semiconductor layer 1300, and a memory cell array may be formed in the channel area CA. The plurality of vertical channel structures VP may extend in the vertical direction VD and penetrate through the first through n-th word lines WL1 through WLn and a plurality of insulating layers formed among the first through n-th word lines WL1 through WLn. The plurality of vertical channel structures VP may be referred to as a vertical pillar. In some example embodiments, each of the plurality of vertical channel structures VP may have a first width VPW in the first horizontal direction HD1. For example, each of the plurality of vertical channel structures VP may have an annular shape. In this case, the first width VPW may correspond to a first channel hole size. However, embodiments are not limited thereto. Each of the plurality of vertical channel structures VP may have an elliptic pillar shape or a quadrangular pillar shape. A plurality of vertical channel structures VP may be spaced apart from each other in the first horizontal direction HD1 and the second horizontal direction HD2.

[0218] In some example embodiments, each of the vertical channel structures VP may include a charge storage layer, a channel layer, and an inner layer. The channel layer may include a silicon material having a first type (e.g., a P type) and may function as a channel area. The inner layer may include an insulating material, such as silicon oxide, or an air gap. The charge storage layer may include a gate insulating layer (or referred to as a “tunneling insulating layer”), a charge trap layer, and/or a blocking insulating layer. For example, the charge storage layer may have an oxide-nitride-oxide (ONO) structure.

[0219] Drains or drain contacts may be respectively provided below the vertical channel structures VP. For example, the drains or the drain contacts may include a silicon material doped with impurities having a second conductivity type (e.g., an N type). Bit lines (e.g., BL in FIG. 22) may be provided below the drain contacts and may respectively connected to the drain contacts through bit line contacts. Each of the bit lines may be connected to the page buffer circuit in the second semiconductor layer 1400 through a pad.

[0220] A plurality of vertical pass transistors, e.g., first and third vertical pass transistors TR1 and TR3 and vertical pass transistors TRs1 and TRs2, may be in the stair area SA. Although only the first and third vertical pass transistors TR1 and TR3 and the vertical pass transistors TRs1 and TRs2 are illustrated in FIG. 25 for convenience of description, the second and fourth through n-th pass transistors TR2 and TR4 through TRn in FIG. 23 may be formed in the stair area SA as vertical pass transistors, and the descriptions of the first and third vertical pass transistors TR1 and TR3 and the vertical pass transistors TRs1 and TRs2 may also be applied to the second and fourth through n-th pass transistors TR2 and TR4 through TRn.

[0221] Each of the first and third vertical pass transistors TR1 and TR3 and the vertical pass transistors TRs1 and TRs2 may be connected to a corresponding line among the first through n-th word lines WL1 through WLn and the string selection lines SSLu and to a corresponding one of a plurality of driving signal lines, e.g., the first through fourth word line driving signal lines SI1 through SI4 and the first through fourth string selection line driving signal lines SS1 through SS4.

For example, the first vertical pass transistor TR1 may be connected between the first word line WL1 and the first word line driving signal line SI1, and the third vertical pass transistor TR3 may be connected between the third word line WL3 and the third word line driving signal line SI3. The vertical pass transistor TRs1 may be connected between the first string selection line SSLu1 and the first string selection line driving signal line SS1, and the vertical pass transistor TRs2 may be connected between the second string selection line SSLu2 and the second string selection line driving signal line SS2.

[0222] Each of the first and third vertical pass transistors TR1 and TR3 and the vertical pass transistors TRs1 and TRs2 may include the vertical channel VC extending in the vertical direction VD. In some example embodiments, a plurality of vertical channels VC may have the same height, e.g., a first height VCH, in the vertical direction VD. In some example embodiments, bottom levels of the vertical channels VC may be higher than a top level of the first word line WL1, which is at the top among the first through n-th word lines WL1 through WLn. For example, the bottom levels of the vertical channels VC may be between the first word line WL1 and the ground selection line GSL.

[0223] The vertical channels VC may have a second width VCW in the first horizontal direction HD1. In some example embodiments, the second width VCW may be greater than the first width WPW of the vertical channel structures VP. Accordingly, a breakdown issue of the first and third vertical pass transistors TR1 and TR3 and the vertical pass transistors TRs1 and TRs2 may be resolved. For example, the second width VCW may be at least about twice the first width VPW. However, embodiments are not limited thereto. The first width VPW and the second width VCW may vary with embodiments.

[0224] In some example embodiments, the vertical channels VC may be formed in the same structure using the same process as the vertical channel structures VP. Therefore, like the vertical channel structures VP, the vertical channels VC may include a charge storage layer, a channel layer, and an inner layer. However, embodiments are not limited thereto. In some example embodiments, the vertical channels VC may include only a channel layer and an inner layer.

[0225] The vertical channels VC respectively included in the first and third vertical pass transistors TR1 and TR3 and the vertical pass transistors TRs1 and TRs2 may be connected in common to the gate GT. In some example embodiments, the gate GT connected in common to the first and third vertical pass transistors TR1 and TR3 and the vertical pass transistors TRs1 and TRs2 may be at the same level as the ground selection line GSL.

[0226] In some example embodiments, the vertical channels VC respectively included in the first and third vertical pass transistors TR1 and TR3 and the vertical pass transistors TRs1 and TRs2 may be respectively connected to different gates. In this case, the different gates may have different lengths in the vertical direction VD, and the first and third vertical pass transistors TR1 and TR3 and the vertical pass transistors TRs1 and TRs2 may have different driving performance.

[0227] In some example embodiments, a first length LG1 of the gate GT may be substantially the same as a second length LG2 of the ground selection line GSL in the vertical direction VD. In some example embodiments, a third length LS1 of an insulating layer between the gate GT and the first word line WL1 may be substantially the same as a fourth length LS2 of an insulating layer between the ground selection line GSL and the first word line WL1 in the vertical direction VD. However, embodiments are not limited thereto. The first length LG1 may be different from the second length LG2, and the third length LS1 may be different from the fourth length LS2.

[0228] In some example embodiments, the second length LG2 of the ground selection line GSL may be substantially the same as a length of each of the first through n-th word lines WL1 through WLn in the vertical direction VD, but embodiments are not limited thereto. In some example embodiments, the second length LG2 may be substantially the same as a length of the string selection line SSLu in the vertical direction VD, but embodiments are not limited thereto.

[0229] The contact CP may be placed in each of the first and third vertical pass transistors TR1 and

TR3 and the vertical pass transistors TRs1 and TRs2. Each of the first and third vertical pass transistors TR1 and TR3 and the vertical pass transistors TRs1 and TRs2 may be connected to a corresponding line among the first through n-th word lines WL1 through WLn and the string selection lines SSLu through the contact CP corresponding thereto. For example, the first vertical pass transistor TR1 may be connected to the first word line WL1 through the contact CP corresponding to the first vertical pass transistor TR1, and the third vertical pass transistor TR3 may be connected to the third word line WL3 through the contact CP corresponding to the third vertical pass transistor TR3. The vertical pass transistor TRs1 may be connected to the first string selection line SSLu1 through the contact CP corresponding to the vertical pass transistor TRs1, and the vertical pass transistor TRs2 may be connected to the second string selection line SSLu2 through the contact CP corresponding to the vertical pass transistor TRs2.

[0230] In some example embodiments, a plurality of contacts CP respectively connected to the vertical channels VC may have the same height, e.g., a second height CPH, in the vertical direction VD. Accordingly, the contacts CP may be easily formed in the memory device 40.

[0231] Referring to FIGS. 25 and 26, the second semiconductor layer 1400 may include a substrate SUB, a first lower insulating layer IL21, and/or a second lower insulating layer IL22. The first semiconductor layer 1300 may be combined with the second semiconductor layer 1400 by C2C wafer bonding. In this case, a plurality of bonding pads PD1a and PD1b may be formed on a first surface of the first semiconductor layer 1300, and a plurality of bonding pads PD2a and PD2b may be formed on a first surface of the second semiconductor layer 1400. The first surface of the first semiconductor layer 1300 may be bonded to the first surface of the second semiconductor layer 1400 through the plurality of bonding pads PD1a, PD1b, PD2a, and PD2b. In some example embodiments, an I/O pad forming process and a back-lap process may be sequentially performed on a second surface opposite the first surface of the first semiconductor layer 1300.

[0232] The gate GT may be connected to a transistor 1440 through an interconnection, which includes a first contact 1310, a metal pattern 1330, and the bonding pad PD1a that are included in the first semiconductor layer 1300 and the bonding pad PD2a, contacts 1410 and 1430, and a metal pattern 1420 that are included in the second semiconductor layer 1400. The first word line driving signal line SI1 may be connected to a transistor 1480 through an interconnection, which includes a contact 1320 and the bonding pad PD1b that are included in the first semiconductor layer 1300 and the bonding pad PD2b, contacts 1450 and 1470, and a metal pattern 1460 that are included in the second semiconductor layer 1400. Also, each of a plurality of driving signal lines (e.g., SI2 through SI4 and SS1 through SS4) except for the first word line driving signal line SI1 may be connected to a transistor through an interconnection, which includes a contact CP and a bonding pad that are included in the first semiconductor layer 1300 and a bonding pad, a contact, and a metal pattern that are included in the second semiconductor layer 1400.

[0233] In some example embodiments, at least a portion of a row decoder (e.g., 1220a in FIG. 23) may be below vertical pass transistors (e.g., TR1, TR3, TRs1, and TRs2) in the vertical direction VD. For example, at least one selected from the mat decoder 1221a and the driving signal line decoder 1222a in FIG. 23 may be below the vertical pass transistors (e.g., TR1, TR3, TRs1, and TRs2) in the vertical direction VD and may include the transistor 1440.

[0234] FIGS. 27A through 27C are diagrams of memory devices including the pass transistor circuit in FIG. 23 respectively, according to example embodiments. Redundant descriptions of like numerals in FIGS. 25, 26 and 27A through 27C will be omitted.

[0235] Referring to FIG. 27A, a memory device 40a may include an upper string selection line SSLd, which are stacked on the string selection lines SSLu. Therefore, the string selection lines SSLu described above may be represented by the lower string selection lines SSLu in FIGS. 27A through 27C. For example, the upper string selection line SSLd may be stacked on the lower string selection lines SSLu in the vertical direction VD. The lower string selection lines SSLu may include a first lower string selection line SSLu1 and a second lower string selection line SSLu2,

which are located at the same level. A plurality of vertical channel structures VP may extend in the vertical direction VD and penetrate through the ground selection line GSL, the first through n-th word lines WL1 through WLn, the upper string selection line SSLd, and/or the lower string selection lines SSLu.

[0236] In the memory device **40a**, some of a plurality of pass transistors (e.g., TRs, TR1 through TRn, and TRg in FIG. 23) may be formed as vertical pass transistors in a first semiconductor layer **1300a**, and the others of the pass transistors may be formed as normal pass transistors in a second semiconductor layer **1400a**. For example, the pass transistor TRg connected to the ground selection line GSL, which is in the same layer as the gate GT among the ground selection line GSL, the first through n-th word lines WL1 through WLn, the upper string selection line SSLd, and the lower string selection lines SSLu, may be formed as a normal pass transistor in the second semiconductor layer **1400a**. The ground selection line GSL may be connected to the pass transistor TRg through an interconnection, which includes a second contact **1311**, a metal pattern **1331**, and a bonding pad PD1c that are included in the first semiconductor layer **1300a** and a bonding pad PD2c, contacts **1411** and **1431**, and a metal pattern **1421** that are included in the second semiconductor layer **1400a**.

[0237] The second contact **1311** may extend in the vertical direction VD to be in contact with the ground selection line GSL and may penetrate through the first through n-th word lines WL1 through WLn, the upper string selection line SSLd, and the lower string selection lines SSLu. The first through n-th word lines WL1 through WLn, the upper string selection line SSLd, and the lower string selection lines SSLu may include the insulating region NT contacting the second contact **1311** and may thus be insulated from the second contact **1311**.

[0238] In the memory device **40a**, the gate GT connected in common to a plurality of vertical pass transistors (e.g., TR1, TR3, TRs1, and TRs2) is formed at the same level as the ground selection line GSL, and therefore, the pass transistor TRg connected to the ground selection line GSL may be formed in the second semiconductor layer **1400a**. However, embodiments are not limited thereto. The pass transistor TRg connected to the ground selection line GSL may be formed in the first semiconductor layer **1300a** as a normal transistor or a vertical pass transistor.

[0239] Referring to FIG. 27B, a memory device **40b** may include a gate GTb forming the third vertical pass transistor TR3 and the vertical pass transistors TRs1 and TRs2. In some example embodiments, a first length LG1b of the gate GTb may be different from a second length LG2b of the ground selection line GSL in the vertical direction VD. For example, the first length LG1b of the gate GTb may be greater than the second length LG2b of the ground selection line GSL. In some example embodiments, a third length LS1b of an insulating layer between the gate GTb and the second word line WL2 may be different from a fourth length LS2b of an insulating layer between the ground selection line GSL and the first word line WL1 in the vertical direction VD.

[0240] When the first length LG1b of the gate GTb in the vertical direction VD increases, a high voltage may be applied to the gate electrode of the third vertical pass transistor TR3 and the vertical pass transistors TRs1 and TRs2, i.e., the gate GTb, and the driving speed of the third vertical pass transistor TR3 and the vertical pass transistors TRs1 and TRs2 may be increased. In addition, a breakdown issue of the first and third vertical pass transistors TR1 and TR3 and the vertical pass transistors TRs1 and TRs2 may be resolved.

[0241] In some example embodiments, the pass transistor TRg and a first pass transistor TR1b of the memory device **40b** may be in a second semiconductor layer **1400b** and may be normal pass transistors. For example, the ground selection line GSL may be connected to the pass transistor TRg through an interconnection, which includes the second contact **1311**, the metal pattern **1331**, and the bonding pad PD1c that are included in a first semiconductor layer **1300b** and the bonding pad PD2c, the contacts **1411** and **1431**, and the metal pattern **1421** that are included in the second semiconductor layer **1400b**. For example, the first word line WL1 may be connected to the first pass transistor TR1b through an interconnection, which includes a third contact **1312**, a metal

pattern **1332**, and a bonding pad **PD1d** that are included in the first semiconductor layer **1300b** and a bonding pad **PD2d**, contacts **1412** and **1432**, and a metal pattern **1422** that are included in the second semiconductor layer **1400b**.

[0242] The third contact **1312** may extend in the vertical direction VD to be in contact with the first word line WL1 and may penetrate through the second through n-th word lines WL2 through WLn, the upper string selection line SSLd, and the lower string selection lines SSLu. Each of the second through n-th word lines WL2 through WLn, the upper string selection line SSLd, and the lower string selection lines SSLu may include the insulating region NT contacting the third contact **1312**. Accordingly, the second through n-th word lines WL2 through WLn, the upper string selection line SSLd, and the lower string selection lines SSLu may be insulated from the third contact **1312**.

[0243] Although it has been described with reference to FIG. 27B that the pass transistor TRg and the first pass transistor TR1b are in the second semiconductor layer **1400b**, embodiments are not limited thereto. When a dummy word line is formed between the ground selection line GSL and the first word line WL1, a pass transistor connected to the dummy word line may be in the second semiconductor layer **1400b**.

[0244] Referring to FIG. 27C, in a memory device **40c**, the gate GT and the ground selection line GSL, which are formed in a first semiconductor layer **1300c**, may be formed of a different material than the first through n-th word lines WL1 through WLn. For example, the gate GT and the ground selection line GSL may include polysilicon and the first through n-th word lines WL1 through WLn may include tungsten. However, this is just an example, and the gate GT and the ground selection line GSL may include various materials.

[0245] Since the gate GT and the ground selection line GSL are formed of a different material than that of the first through n-th word lines WL1 through WLn in the memory device **40c**, when the ground selection line GSL, the second through n-th word lines WL2 through WLn, the upper string selection line SSLd, and the lower string selection lines SSLu are partially etched to form the word line cut region WLC, the gate GT and the ground selection line GSL may limit etching and prevent overetch.

[0246] FIG. 28 is a cross-sectional view illustrating a memory device according to some embodiments.

[0247] Referring to FIG. 28, a memory device **2000** may have a chip-to-chip (C2C) structure. The C2C structure may refer to a structure formed by manufacturing an upper chip including a cell region (or memory cell region) CELL on a first wafer, manufacturing a lower chip including a peripheral circuit region PERI on a second wafer, different from the first wafer, and then connecting the upper chip and the lower chip in a bonding manner. For example, the bonding manner may include a method of electrically connecting a bonding metal formed on an uppermost metal layer of the upper chip and a bonding metal formed on an uppermost metal layer of the lower chip. For example, when the bonding metals may be formed of copper (Cu), the bonding manner may be a Cu—Cu bonding, and the bonding metals may also be formed of aluminum or tungsten.

[0248] Each of the peripheral circuit region PERI and the cell region CELL of the memory device **2000** may include an external pad bonding area PA, a word line bonding area WLBA, and a bit line bonding area BLBA.

[0249] The peripheral circuit region PERI may include a first substrate **2210**, an interlayer insulating layer **2215**, a plurality of circuit elements **2220a**, **2220b**, and **2220c** formed on the first substrate **2210**, first metal layers **2230a**, **2230b**, and **2230c** respectively connected to the plurality of circuit elements **2220a**, **2220b**, and **2220c**, and second metal layers **2240a**, **2240b**, and **2240c** formed on the first metal layers **2230a**, **2230b**, and **2230c**. Each of the circuit elements **2220a**, **2220b**, and **2220c** may include one or more transistors. In an example embodiment, the first metal layers **2230a**, **2230b**, and **2230c** may be formed of tungsten having relatively high resistance, and the second metal layers **2240a**, **2240b**, and **2240c** may be formed of copper having relatively low resistance.

[0250] In an example embodiment illustrate in FIG. 28, although the first metal layers **2230a**, **2230b**, and **2230c** and the second metal layers **2240a**, **2240b**, and **2240c** are shown and described, they are not limited thereto, and one or more metal layers may be further formed on the second metal layers **2240a**, **2240b**, and **2240c**. At least a portion of the one or more metal layers formed on the second metal layers **2240a**, **2240b**, and **2240c** may be formed of aluminum or the like having a lower resistance than those of copper forming the second metal layers **2240a**, **2240b**, and **2240c**.

[0251] The interlayer insulating layer **2215** may be disposed on the first substrate **2210** and cover the plurality of circuit elements **2220a**, **2220b**, and **2220c**, the first metal layers **2230a**, **2230b**, and **2230c**, and the second metal layers **2240a**, **2240b**, and **2240c**. The interlayer insulating layer **2215** may include an insulating material such as silicon oxide, silicon nitride, or the like.

[0252] Lower bonding metals **2271b** and **2272b** may be formed on the second metal layer **2240b** in the word line bonding area WLBA. In the word line bonding area WLBA, the lower bonding metals **2271b** and **2272b** in the peripheral circuit region PERI may be electrically connected to upper bonding metals **2371b** and **2372b** in the cell region CELL in a bonding manner, and the lower bonding metals **2271b** and **2272b** and the upper bonding metals **2371b** and **2372b** may be formed of aluminum, copper, tungsten, or the like.

[0253] The upper bonding metals **2371b** and **2372b** in the cell region CELL may be referred as first metal pads and the lower bonding metals **2271b** and **2272b** in the peripheral circuit region PERI may be referred as second metal pads. In some examples, the first metal pads and the second metal pads may be connected with each other in the bonding manner.

[0254] The cell region CELL may include at least one memory block. The cell region CELL may include a second substrate **2310** and a common source line **2320**. On the second substrate **2310**, a plurality of word lines **2331** to **2338** (i.e., **2330**) may be stacked in a direction (a Z-axis direction), perpendicular to an upper surface of the second substrate **2310**. At least one string select line and at least one ground select line may be arranged on and below the plurality of word lines **2330**, respectively, and the plurality of word lines **2330** may be disposed between the at least one string select line and the at least one ground select line.

[0255] In the bit line bonding area BLBA, a channel structure CHS may extend in a direction, perpendicular to the upper surface of the second substrate **2310**, and pass through the plurality of word lines **2330**, the at least one string select line, and the at least one ground select line. The channel structure CHS may include a data storage layer, a channel layer, a buried insulating layer, and the like, and the channel layer may be electrically connected to a third metal layer **2350c** and a fourth metal layer **2360c**. For example, the third metal layer **2350c** may be a bit line contact, and the fourth metal layer **2360c** may be a bit line. In an example embodiment, the bit line **2360c** may extend in a first direction (a Y-axis direction), parallel to the upper surface of the second substrate **2310**.

[0256] In an example embodiment illustrated in FIG. 28, an area in which the channel structure CHS, the bit line **2360c**, and the like are disposed may be defined as the bit line bonding area BLBA. In the bit line bonding area BLBA, the bit line **2360c** may be electrically connected to the circuit elements **2220c** providing a page buffer circuit **2393** in the peripheral circuit region PERI. For example, the bit line **2360c** may be connected to upper bonding metals **2371c** and **2372c** in the cell region CELL, and the upper bonding metals **2371c** and **2372c** may be connected to lower bonding metals **2271c** and **2272c** connected to the circuit elements **2220c** of the page buffer circuit **2393**.

[0257] In the word line bonding area WLBA, the plurality of word lines **2330** may extend in a second direction (an X-axis direction), parallel to the upper surface of the second substrate **2310**, and may be connected to a plurality of cell contact plugs **2341** to **2347** (i.e., **2340**). The plurality of word lines **2330** and the plurality of cell contact plugs **2340** may be connected to each other in pads provided by at least a portion of the plurality of word lines **2330** extending in different lengths in the second direction. A third metal layer **2350b** and a fourth metal layer **2360b** may be connected to

an upper portion of the plurality of cell contact plugs **2340** connected to the plurality of word lines **2330**, sequentially. The plurality of cell contact plugs **2340** may be connected to the circuit region PERI by the upper bonding metals **2371b** and **2372b** of the cell region CELL and the lower bonding metals **2271b** and **2272b** of the peripheral circuit region PERI in the word line bonding area WLBA.

[0258] The plurality of cell contact plugs **2340** may be electrically connected to the circuit elements **2220b** providing a row decoder **2394** in the peripheral circuit region PERI. In an example embodiment, operating voltages of the circuit elements **2220b** providing the row decoder **2394** may be different than operating voltages of the circuit elements **2220c** providing the page buffer circuit **2393**. For example, operating voltages of the circuit elements **2220c** providing the page buffer **2393** may be greater than operating voltages of the circuit elements **2220b** providing the row decoder **2394**.

[0259] A common source line contact plug **2380** may be disposed in the external pad bonding area PA. The common source line contact plug **2380** may be formed of a conductive material such as a metal, a metal compound, polysilicon, or the like, and may be electrically connected to the common source line **2320**. A third metal layer **2350a** and a fourth metal layer **2360a** may be stacked on an upper portion of the common source line contact plug **2380**, sequentially. For example, an area in which the common source line contact plug **2380**, the third metal layer **2350a**, and the fourth metal layer **2360a** are disposed may be defined as the external pad bonding area PA.

[0260] Input-output pads **2205** and **2305** may be disposed in the external pad bonding area PA. Referring to FIG. **28**, a lower insulating film **2201** covering a lower surface of the first substrate **2210** may be formed below the first substrate **2210**, and a first input-output pad **2205** may be formed on the lower insulating film **2201**. The first input-output pad **2205** may be connected to at least one of the plurality of circuit elements **2220a**, **2220b**, and **2220c** disposed in the peripheral circuit region PERI through a first input-output contact plug **2203**, and the first input-output pad **2205** may be separated from the first substrate **2210** by the lower insulating film **2201**. In addition, a side insulating film may be disposed between the first input-output contact plug **2203** and the first substrate **2210** to electrically separate the first input-output contact plug **2203** and the first substrate **2210**.

[0261] Referring to FIG. **28**, an upper insulating film **2301** covering the upper surface of the second substrate **2310** may be formed on the second substrate **2310**, and a second input-output pad **2305** may be disposed on the upper insulating layer **2301**. The second input-output pad **2305** may be connected to at least one of the plurality of circuit elements **2220a**, **2220b**, and **2220c** disposed in the peripheral circuit region PERI through a second input-output contact plug **2303**.

[0262] According to embodiments, the second substrate **2310** and the common source line **2320** may not be disposed in an area in which the second input-output contact plug **2303** is disposed. Also, the second input-output pad **2305** may not overlap the word lines **2330** in the third direction (the Z-axis direction). Referring to FIG. **28**, the second input-output contact plug **2303** may be separated from the second substrate **2310** in a direction, parallel to the upper surface of the second substrate **2310**, and may pass through an interlayer insulating layer **2315** of the cell region CELL to be connected to the second input-output pad **2305** and an upper bonding metal **2372a** in the cell region CELL.

[0263] According to embodiments, the first input-output pad **2205** and the second input-output pad **2305** may be selectively formed. For example, the memory device **2000** may include only the first input-output pad **2205** disposed on the lower insulating film **2201** in contact with the first substrate **2210** or the second input-output pad **2305** disposed on the upper insulating film **2301** in contact with the second substrate **2310**. Alternatively, the memory device **2000** may include both the first input-output pad **2205** and the second input-output pad **2305**.

[0264] A metal pattern in an uppermost metal layer may be provided as a dummy pattern or the uppermost metal layer may be absent, in each of the external pad bonding area PA and the bit line

bonding area BLBA, respectively included in the cell region CELL and the peripheral circuit region PERI.

[0265] In the external pad bonding area PA, the memory device **2000** may include a lower metal pattern **2273a**, corresponding to the upper metal pattern **2372a** formed in an uppermost metal layer of the cell region CELL, and having the same shape as the upper metal pattern **2372a** of the cell region CELL, in an uppermost metal layer of the peripheral circuit region PERI. In the peripheral circuit region PERI, the lower metal pattern **2273a** formed in the uppermost metal layer of the peripheral circuit region PERI may not be connected to a contact. Similarly, in the external pad bonding area PA, an upper metal pattern, corresponding to the lower metal pattern formed in an uppermost metal layer of the peripheral circuit region PERI, and having the same shape as a lower metal pattern of the peripheral circuit region PERI, may be formed in an uppermost metal layer of the cell region CELL.

[0266] The lower bonding metals **2271b** and **2272b** may be formed on the second metal layer **2240b** in the word line bonding area WLBA. In the word line bonding area WLBA, the lower bonding metals **2271b** and **2272b** of the peripheral circuit region PERI may be electrically connected to the upper bonding metals **2371b** and **2372b** of the cell region CELL by a Cu—Cu bonding.

[0267] Further, the bit line bonding area BLBA, an upper metal pattern **2392**, corresponding to a lower metal pattern **2252** formed in the uppermost metal layer of the peripheral circuit region PERI, and having the same shape as the lower metal pattern **2252** of the peripheral circuit region PERI, may be formed in an uppermost metal layer of the cell region CELL. A contact may not be formed on the upper metal pattern **2392** formed in the uppermost metal layer of the cell region CELL.

[0268] In an example embodiment, corresponding to a metal pattern formed in an uppermost metal layer in one of the cell region CELL and the peripheral circuit region PERI, a reinforcement metal pattern having the same shape as the metal pattern may be formed in an uppermost metal layer in another one of the cell region CELL and the peripheral circuit region PERI, and a contact may not be formed on the reinforcement metal pattern.

[0269] In an example embodiment, the nonvolatile memory device **2000**, such as described in FIG. **28**, can operate and can include device components according to one or more of the example embodiments described in FIGS. **1** to **26** and **27A** to **27C** previously.

[0270] A nonvolatile memory device or a storage device according to an embodiment of the inventive concept may be packaged using various package types or package configurations.

[0271] The present disclosure may be applied to various electronic devices including a nonvolatile memory device. For example, the present disclosure may be applied to systems such as be a mobile phone, a smart phone, a personal digital assistant (PDA), a portable multimedia player (PMP), a digital camera, a camcorder, personal computer (PC), a server computer, a workstation, a laptop computer, a digital TV, a set-top box, a portable game console, a navigation system, etc.

[0272] The foregoing is illustrative of exemplary embodiments and is not to be construed as limiting thereof. Although a few exemplary embodiments have been described, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of the present invention. Accordingly, all such modifications are intended to be included within the scope of the present invention as defined in the claims. Therefore, it is to be understood that the foregoing is illustrative of various exemplary embodiments and is not to be construed as limited to the specific exemplary embodiments disclosed, and that modifications to the disclosed exemplary embodiments, as well as other exemplary embodiments, are intended to be included within the scope of the appended claims.

Claims

1. A nonvolatile memory device comprising: a memory cell region including a first metal pad; a peripheral circuit region including a second metal pad and vertically connected to the memory cell region by the first metal pad and the second metal pad; a memory cell array in the memory cell region, the memory cell array including a plurality of mats corresponding to different word-lines, each of the plurality of mats including a plurality of cell strings perpendicular to a substrate respectively, wherein: a first cell string of a first mat of the plurality of mats is connected to a plurality of first word-lines, a first bit-line, a first string selection line and a first ground selection line, a second cell string of a second mat of the plurality of mats is connected to a plurality of second word-lines, a second bit-line, a second string selection line and a second ground selection line, and each of the first and second cell strings includes at least one ground selection transistor, a plurality of memory cells, and a plurality of string selection transistors coupled in series; and a page buffer circuit in the peripheral circuit region, the page buffer circuit configured to sense a first data in the first cell string through the first bit-line at a first sensing time and sense a second data at in the second cell string through the second bit-line at a second sensing time, wherein the page buffer circuit is configured to apply a different or the same voltage to at least one of the first bit-line and the second bit-line through the first metal pad and the second metal pad based on whether a memory operation of the nonvolatile memory device is performed for only one of the first and second mats in a single mat mode or whether the memory operation is performed for both of the first and second mats simultaneously in a multi-mat mode.
2. The nonvolatile memory device of claim 1, wherein the first sensing time is the same as the second sensing time, wherein the page buffer circuit is configured to apply a first voltage to the first bit-line in the single mat mode, and wherein the page buffer circuit is configured to apply a second voltage to the first bit-line and the second bit-line in the multi-mat mode.
3. The nonvolatile memory device of claim 2, wherein a voltage level of the first voltage is greater than a voltage level of the second voltage before the first sensing time.
4. The nonvolatile memory device of claim 2, wherein a voltage level of the first voltage is smaller than a voltage level of the second voltage after the first sensing time.
5. The nonvolatile memory device of claim 2, wherein a voltage level of the first voltage is the same as a voltage level of the second voltage at the first sensing time.
6. The nonvolatile memory device of claim 1, wherein the first sensing time is different from the second sensing time, wherein the page buffer circuit is configured to apply a first voltage to the first bit-line during a first time interval in the single mat mode, and wherein the page buffer circuit is configured to apply a second voltage to the first bit-line and the second bit-line during a second time interval in the multi-mat mode.
7. The nonvolatile memory device of claim 6, wherein the second time interval is longer than the first time interval.
8. The nonvolatile memory device of claim 6, wherein a voltage level of the first voltage is the same as a voltage level of the second voltage.
9. A nonvolatile memory device comprising: a memory cell region including a first metal pad; a peripheral circuit region including a second metal pad and vertically connected to the memory cell region by the first metal pad and the second metal pad; a memory cell array in the memory cell region, the memory cell array including a plurality of mats corresponding to different word-lines, each of the plurality of mats including a plurality of cell strings perpendicular to a substrate respectively, wherein: a first cell string of a first mat of the plurality of mats is connected to a plurality of first word-lines, a first bit-line, a first string selection line and a first ground selection line, a second cell string of a second mat of the plurality of mats is connected to a plurality of second word-lines, a second bit-line, a second string selection line and a second ground selection

line, and each of the first and second cell strings includes at least one ground selection transistor, a plurality of memory cells, and a plurality of string selection transistors coupled in series; a row decoder in the peripheral circuit region, the row decoder configured to apply a voltage to a third word-line among the plurality of first and second word-lines through the first metal pad and the second metal pad based on whether a memory operation of the nonvolatile memory device is performed for only one of the first and second mats in a single mat mode or whether the memory operation is performed for both of the first and second mats simultaneously in a multi-mat mode; and a page buffer circuit in the peripheral circuit region, the page buffer circuit configured to sense a first data in the first cell string through the first bit-line at a first sensing time and sense a second data at in the second cell string through the second bit-line at a second sensing time.

10. The nonvolatile memory device of claim 9, wherein the third word-line is a selected word-line, wherein the first sensing time is the same as the second sensing time, wherein the row decoder is configured to apply a first voltage to the third word-line through the first metal pad and the second metal pad in the single mat mode, and wherein the row decoder is configured to apply a second voltage to the third word-line through the first metal pad and the second metal pad in the multi-mat mode.

11. The nonvolatile memory device of claim 10, wherein a voltage level of the first voltage is greater than a voltage level of the second voltage before the first sensing time.

12. The nonvolatile memory device of claim 10, wherein a voltage level of the first voltage is smaller than a voltage level of the second voltage after the first sensing time.

13. The nonvolatile memory device of claim 10, wherein a voltage level of the first voltage is the same as a voltage level of the second voltage at the first sensing time.

14. The nonvolatile memory device of claim 9, wherein the third word-line is a selected word-line, wherein the first sensing time is different from the second sensing time, wherein the row decoder is configured to apply a first voltage to the third word-line during a first time interval through the first metal pad and the second metal pad in the single mat mode, and wherein the row decoder is configured to apply a second voltage to the third word-line during a second time interval through the first metal pad and the second metal pad in the multi-mat mode.

15. The nonvolatile memory device of claim 14, wherein the second time interval is longer than the first time interval.

16. The nonvolatile memory device of claim 14, wherein a voltage level of the first voltage is the same as a voltage level of the second voltage.

17. A method of operating a nonvolatile memory device, wherein the nonvolatile memory device includes: a memory cell region including a first metal pad; a peripheral circuit region including a second metal pad and vertically connected to the memory cell region by the first metal pad and the second metal pad; and a memory cell array in the memory cell region, the memory cell array including a plurality of mats corresponding to different word-lines, each of the plurality of mats including a plurality of cell strings perpendicular to a substrate respectively, wherein: a first cell string of a first mat of the plurality of mats is connected to a plurality of first word-lines, a first bit-line, a first string selection line and a first ground selection line, a second cell string of a second mat of the plurality of mats is connected to a plurality of second word-lines, a second bit-line, a second string selection line and a second ground selection line, and each of the first and second cell strings includes at least one ground selection transistor, a plurality of memory cells, and a plurality of string selection transistors coupled in series, the method comprising: sensing, by a page buffer circuit in the peripheral circuit region, sense a first data in the first cell string through the first bit-line at a first sensing time and a second data at in the second cell string through the second bit-line at a second sensing time; and applying, by the page buffer circuit, a different or the same voltage to at least one of the first bit-line and the second bit-line through the first metal pad and the second metal pad based on whether a memory operation of the nonvolatile memory device is performed for only one of the first and second mats in a single mat mode or whether the memory operation is

performed for both of the first and second mats simultaneously in a multi-mat mode.

18. The method of claim 17, wherein the first sensing time is the same as the second sensing time, wherein applying the different or the same voltage includes: applying a first voltage to the first bit-line in the single mat mode; and applying a second voltage to the first bit-line and the second bit-line in the multi-mat mode, wherein a voltage level of the first voltage is greater than a voltage level of the second voltage before the first sensing time, and wherein the voltage level of the first voltage is smaller than the voltage level of the second voltage after the first sensing time.

19. The method of claim 17, wherein the first sensing time is different from the second sensing time, and wherein applying the different or the same voltage includes: applying a first voltage to the first bit-line during a first time interval in the single mat mode; and applying a second voltage to the first bit-line and the second bit-line during a second time interval in the multi-mat mode.

20. The method of claim 19, wherein the second time interval is longer than the first time interval.
