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(54) **METHODS AND APPARATUSES INCLUDING AN ASYMMETRIC ASSIST DEVICE**

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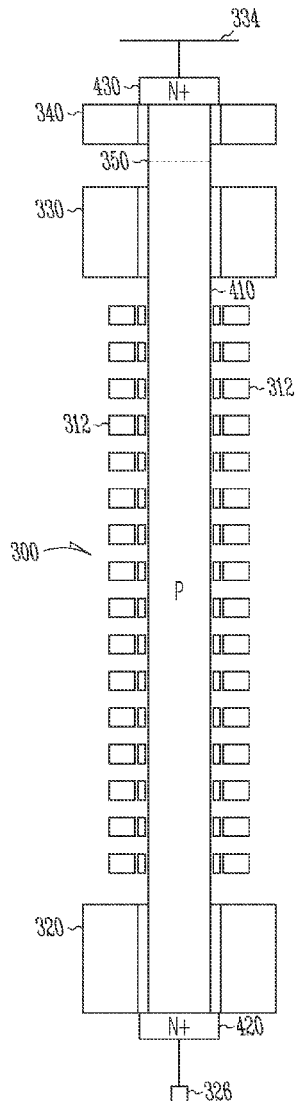
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(57) **ABSTRACT**

Apparatuses and methods have been disclosed. One such apparatus includes a plurality of memory cells that can be formed at least partially surrounding a semiconductor pillar. A select device can be coupled to one end of the plurality of memory cells and at least partially surround the pillar. An asymmetric assist device can be coupled between the select device and one of a source connection or a drain connection. The asymmetric assist device can have a portion that at least partially surrounds the pillar and another portion that at least partially surrounds the source or drain connection.



<u>ERASE</u>	<u>SENSE</u>
20V	0.5V
16V	0.5V
16V	0V
0V	V _{PASS}
0V	V _{PASS}
0V	V _{READ}
0V	V _{PASS}
16V	0V
20V	0V

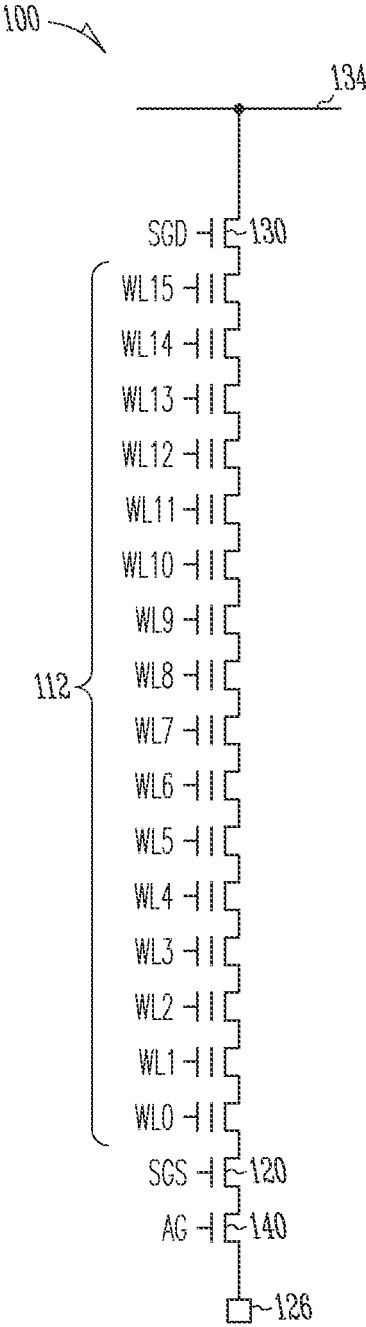


Fig. 1

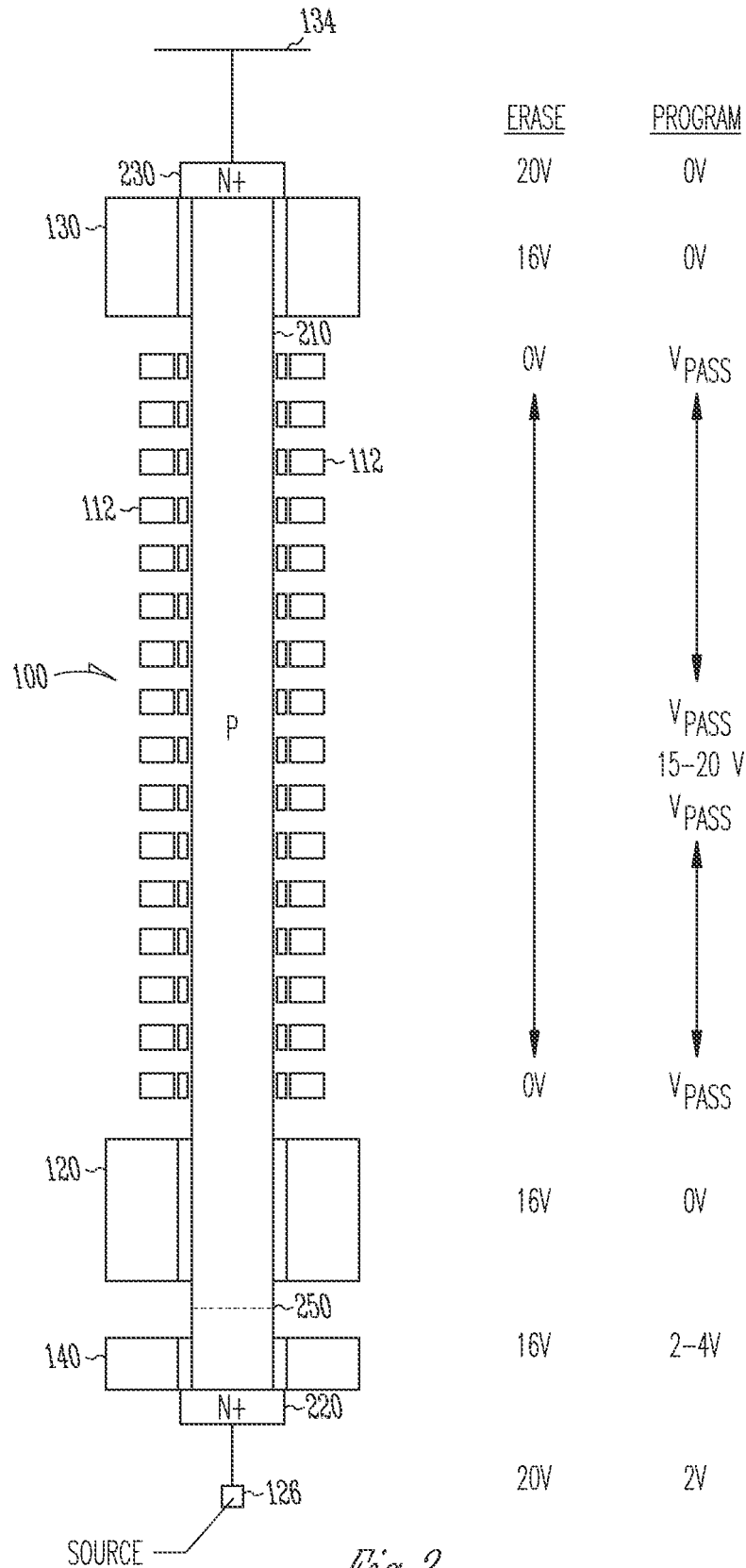


Fig. 2

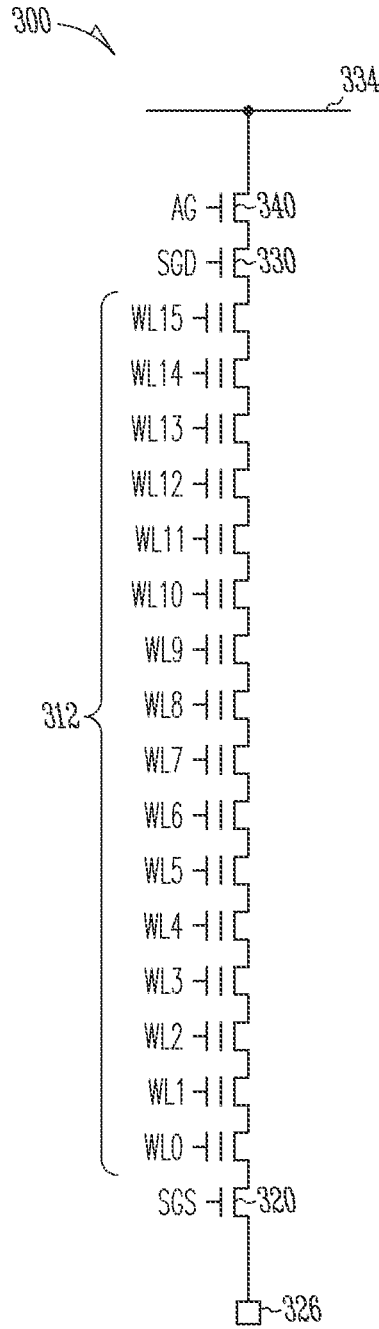


Fig. 3

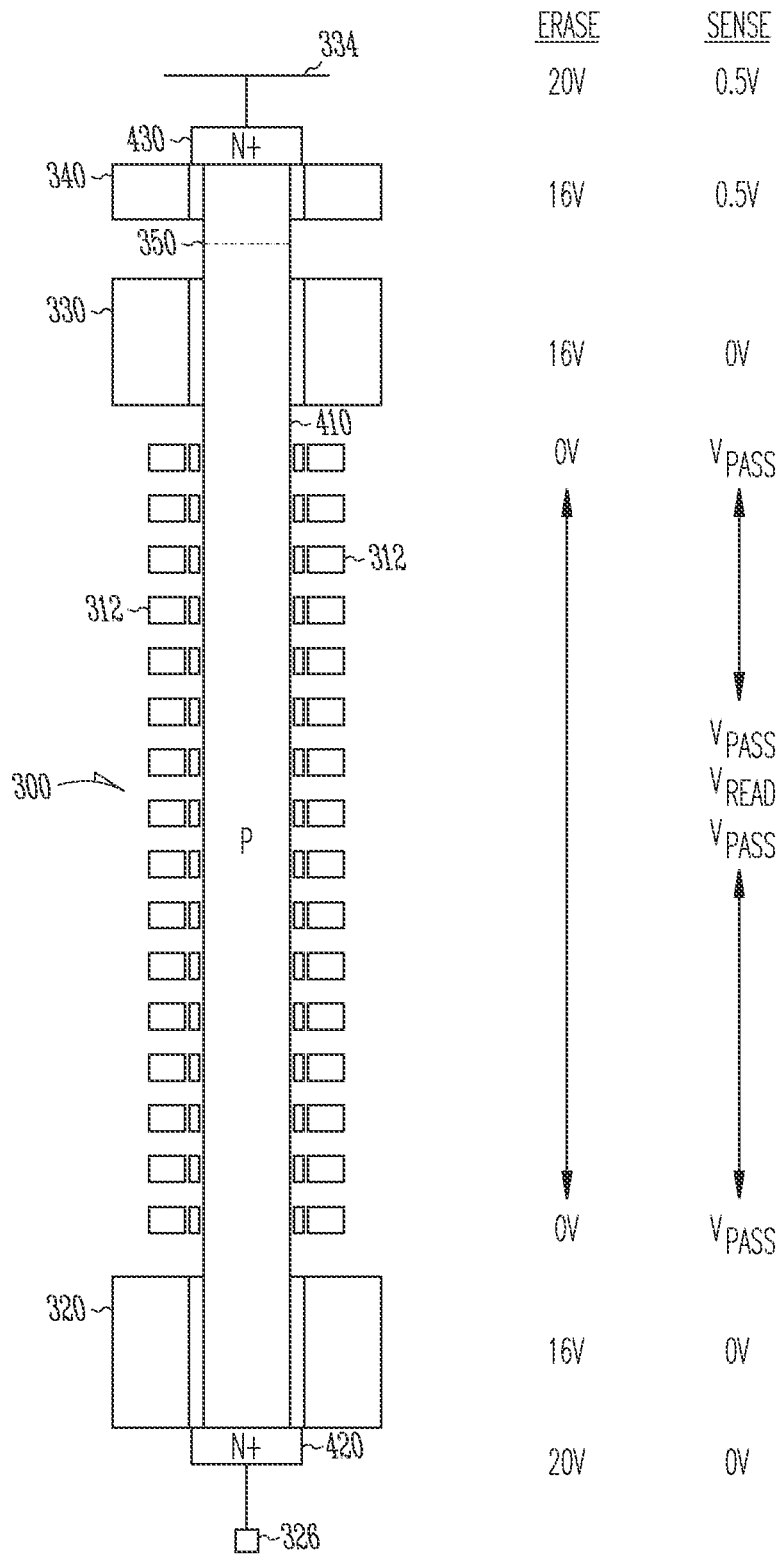


Fig. 4

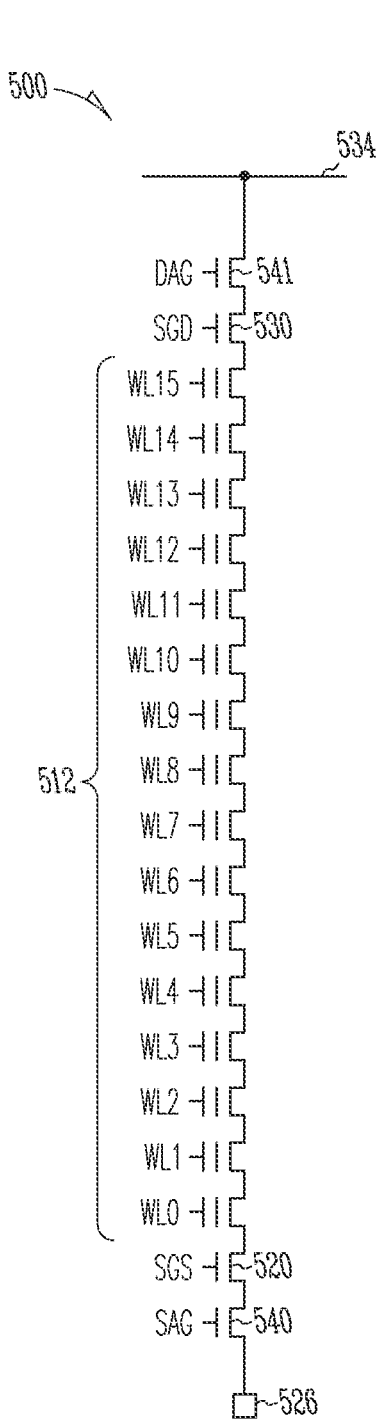


Fig. 5

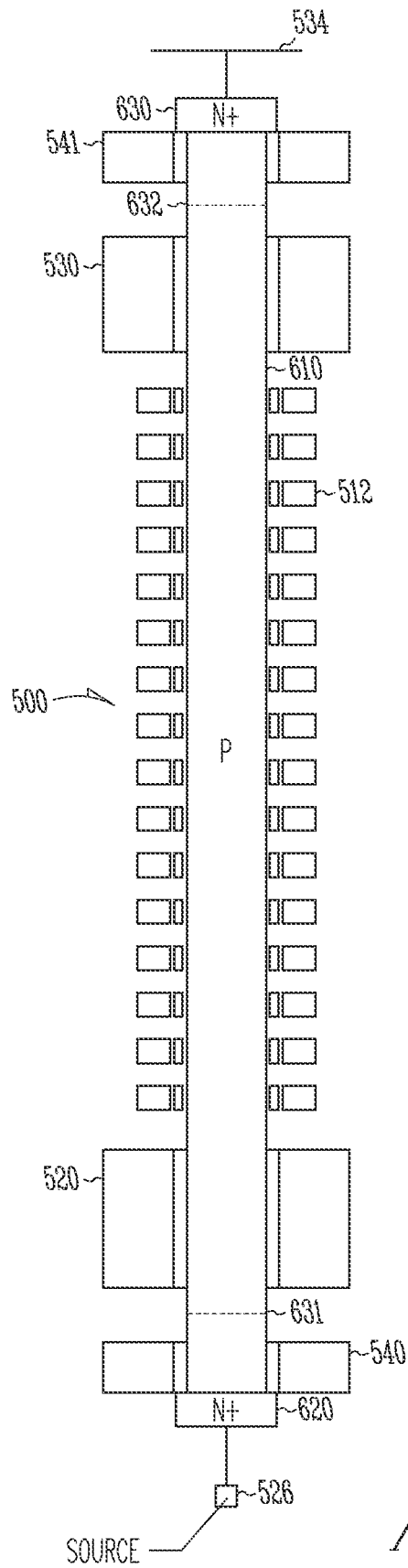


Fig. 6

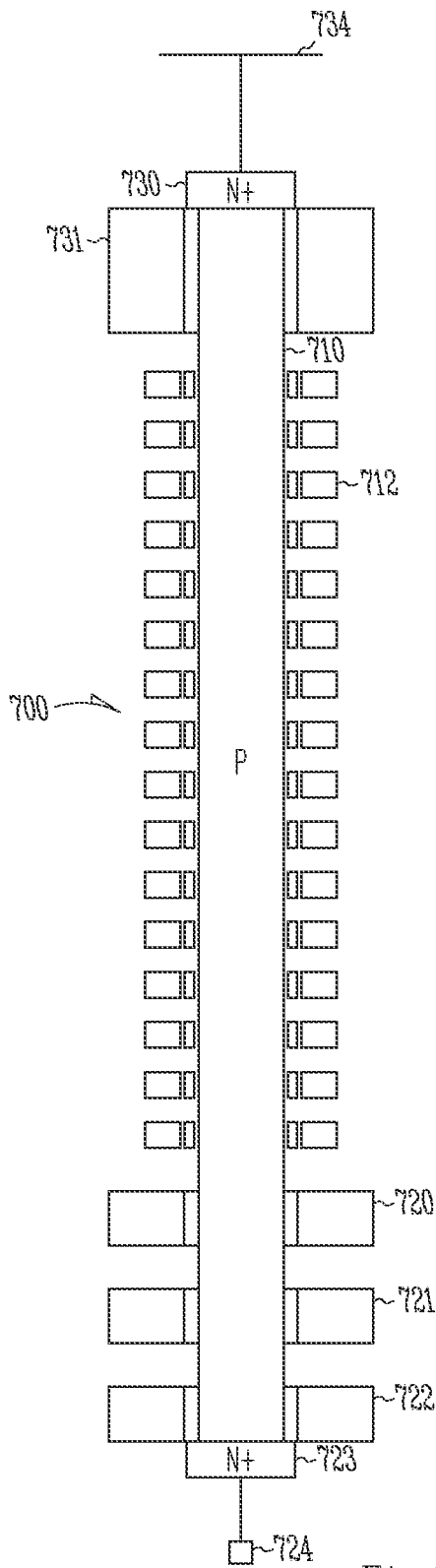


Fig. 7

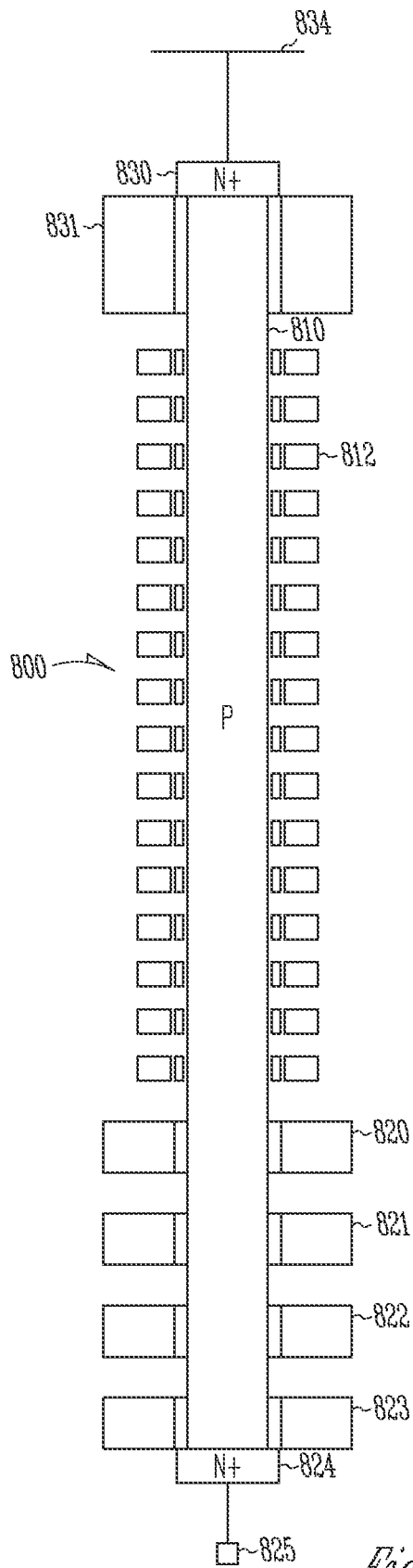


Fig. 8

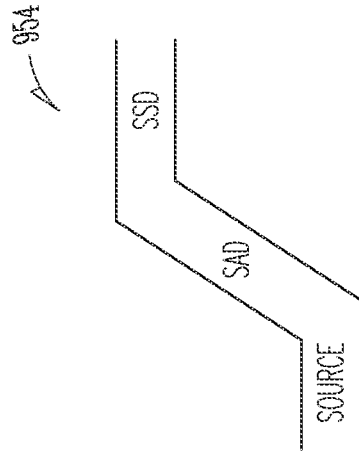
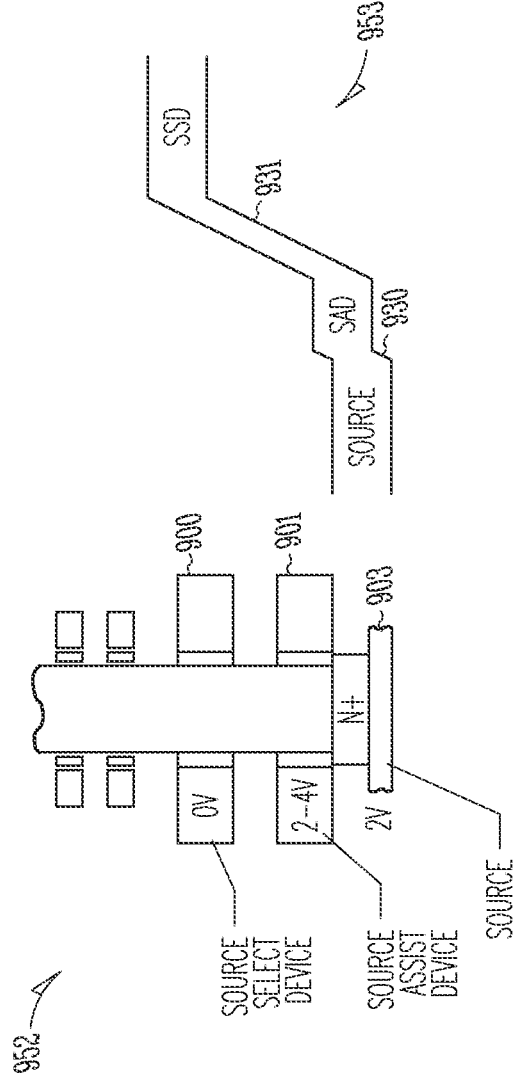
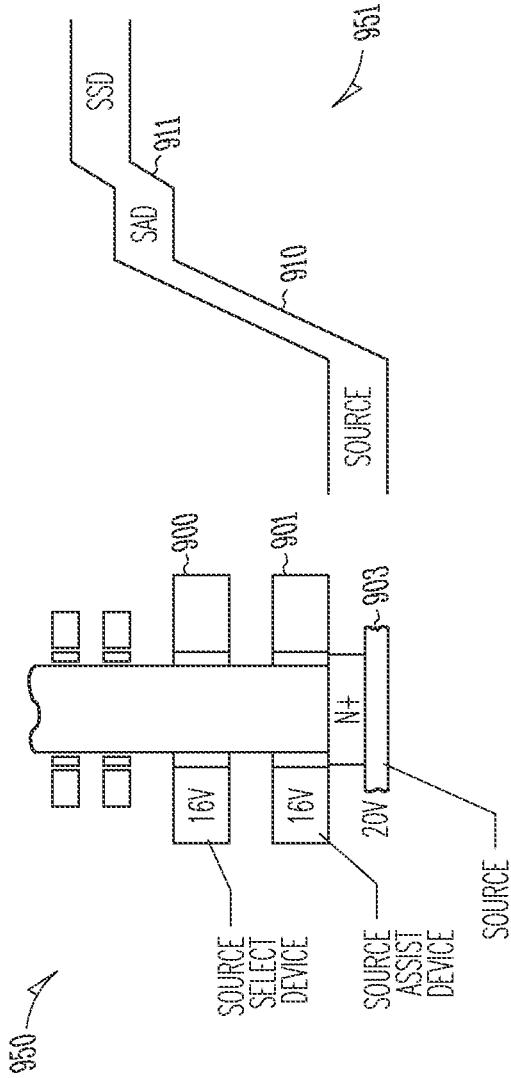


Fig. 9

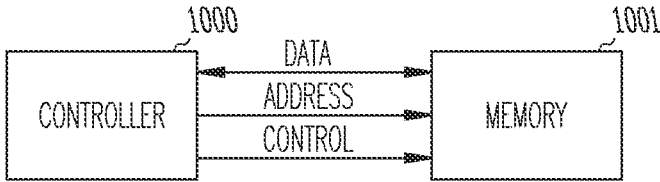


Fig. 10

METHODS AND APPARATUSES INCLUDING AN ASYMMETRIC ASSIST DEVICE

PRIORITY APPLICATION

[0001] This application is a continuation of U.S. application Ser. No. 16/397,731, filed Apr. 29, 2019, which is a continuation of U.S. application Ser. No. 15/863,324, filed Jan. 5, 2018, now issued as U.S. Pat. No. 10,297,325, which is a continuation of U.S. application Ser. No. 14/171,426, filed Feb. 3, 2014, now issued as U.S. Pat. No. 9,875,801, each of which are incorporated herein by reference in their entireties.

BACKGROUND

[0002] Memory devices are typically provided as internal, semiconductor, integrated circuits in apparatuses such as computers or other electronic devices. There are many different types of memory including random-access memory (RAM), read only memory (ROM), dynamic random access memory (DRAM), synchronous dynamic random access memory (SDRAM), and non-volatile (e.g., flash) memory.

[0003] In a continuing process of forming ever increasing number of memory cells on an integrated circuit, memory manufacturers have begun fabrication of three-dimensional (3D) memory formed using semiconductor pillars. Some 3D vertical memory architectures include polysilicon channels that can introduce several deleterious effects relative to a planar memory equivalent.

[0004] For example, bulk traps/defects in the polysilicon channel of vertical memory architectures can give rise to relatively large reverse-biased junction leakage and gate-induced drain leakage (GIDL) currents. The same junctions in the vertical memory architecture typically provide low reverse biased off-state leakage under some bias conditions. These junctions can also act as current supplies to provide high junction leakage for other array operations that use similar bias conditions. This conflicting requirement can result in limiting the operating margin for memory array operations (e.g., erase, program, read).

[0005] Thus, there are conflicting specifications for vertical memory architecture that can impose a series of fundamental engineering trade-offs. There are general needs to improve operating margins while reducing GIDL current.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1 illustrates a schematic diagram of an embodiment of a string of memory cells incorporating a source assist device.

[0007] FIG. 2 illustrates a cross-sectional view of an embodiment of a semiconductor construction of the string of memory cells in accordance with the embodiment of FIG. 1.

[0008] FIG. 3 illustrates a schematic diagram of an embodiment of a string of memory cells incorporating a drain assist device.

[0009] FIG. 4 illustrates a cross-sectional view of an embodiment of a semiconductor construction of the string of memory cells in accordance with the embodiment of FIG. 3.

[0010] FIG. 5 illustrates a schematic diagram of an embodiment of a string of memory cells incorporating a drain assist device and a source assist device.

[0011] FIG. 6 illustrates a cross-sectional view of an embodiment of a semiconductor construction of the string of memory cells in accordance with the embodiment of FIG. 5.

[0012] FIG. 7 illustrates a cross-sectional view of an embodiment of a semiconductor construction of a string of memory cells incorporating a plurality of source select devices and a source assist device.

[0013] FIG. 8 illustrates a cross-sectional view of an embodiment of a semiconductor construction of a string of memory cells incorporating a plurality of source select devices and a plurality of source assist devices.

[0014] FIG. 9 illustrates diagrams of examples of junction voltage differences during memory operations in accordance with the embodiment of FIGS. 1 and 2.

[0015] FIG. 10 illustrates a block diagram of an apparatus in accordance with the embodiments of FIGS. 1-8.

DETAILED DESCRIPTION

[0016] The following disclosure refers to NAND non-volatile memory for the purposes of illustration only. The present disclosure is not limited to any one type of memory. For example, the memory might include non-volatile memory (e.g., NAND Flash, NOR Flash, phase change memory (PCM)) or volatile memory (e.g., DRAM, SRAM).

[0017] The following embodiments show strings of memory cells having 16 memory cells. This is for purposes of illustration only as the embodiments are not limited to any particular quantity of memory cells. Similarly, the following embodiments show only a single memory cell pillar for purposes of illustration only. The embodiments are not limited to any particular quantity of memory cell pillars.

[0018] FIG. 1 illustrates a schematic diagram of an embodiment of a string of memory cells 100 that can incorporate a source assist device 140 (e.g., vertical assist device, assist gate, transistor, etc.). The string of memory cells 100 can be one of multiple strings of memory cells in a block of memory cells in a memory device, such as a NAND memory device.

[0019] The string of memory cells 100 can include a source select device 120 (e.g., source select gate transistor) in series with the source assist device 140. Both the source select device 120 and the source assist device 140 may be n-channel transistors coupled between a memory cell 112 at one end of the string of memory cells 100 and a common source 126. As discussed subsequently with reference to FIG. 2, the source assist device 140 can be an asymmetric transistor.

[0020] The common source 126 may comprise, for example, a layer of commonly doped semiconductor material and/or other conductive material. The common source 126 can be coupled to a reference voltage V_{ss} (e.g., ground) or a voltage source (e.g., a charge pump circuit not shown).

[0021] At the other end of the string of memory cells 100, a drain select device 130 (e.g., drain select gate transistor) may be an n-channel transistor coupled between one of the memory cells 112 and a data line (e.g., bit line) 134. The data line 134 can eventually be coupled to sense circuitry (not shown) for sensing (e.g., reading) a state of a selected memory cell 112.

[0022] Each memory cell 112 may comprise, for example, a floating gate transistor or a charge trap transistor. Each memory cell 112 can be a single level cell (SLC) for storing two bits of data or a multiple level cell (MLC) for storing two or more bits of data.

[0023] The memory cells 112, the source select device 120, the source assist device 140, and the drain select device 130 can be controlled by signals on their respective control

gates. The signals on the control gates of the memory cells **112** can be provided on access lines (e.g., word lines) WL-WL**15**. In an embodiment, the control gates of memory cells in a row of memory cells can at least partially form an access line.

[0024] The source select device **120** and the source assist device **140** can receive control signals to substantially control conduction between the string of memory cells **100** and the common source **126**. The drain select device **130** can receive a control signal that controls the drain select device **130** so that the drain select device **130** can be used to select or deselect the string **100**.

[0025] FIG. 2 illustrates a cross-sectional view of an embodiment of a semiconductor pillar of the string of memory cells **100** of FIG. 1 that can extend from a substrate (not shown). Portions (e.g., gates) of the memory cells **112**, source select device **120**, source assist device **140**, and the drain select device **130** can at least partially surround (e.g., surround or partially surround) a semiconductor material **210**. The semiconductor material **210**, in one embodiment, can comprise a pillar of p-type polysilicon and can operate as a channel for the memory cells **112**, the source select device **120**, the assist device **140**, and the drain select device **130**. The memory cells **112**, the source select device **120**, the assist device **140**, and the drain select device **130** can thus be associated with the pillar of semiconductor material **210**.

[0026] The pillar of semiconductor material **210** can extend between a source cap **220** (e.g., n+ type polysilicon) and a drain cap **230** (e.g., n+ type polysilicon). The source cap **220** can be in electrical contact with the pillar of semiconductor material **210** and can form a doped (e.g., p-n) junction with the semiconductor material **210**. The drain cap **230** can be in electrical contact with the pillar of semiconductor material **210** and can form a doped (e.g., p-n) junction with the semiconductor material **210**. A doped junction can also be an n+/n- junction. The source cap **220** can be a source connection for the pillar of semiconductor material **210** and the drain cap **230** can be a drain connection for the pillar of semiconductor material **210**. The source cap **220** can be coupled to the common source **126**. The drain cap **230** can be coupled to the data line **134**.

[0027] The source assist device **140** can be an asymmetric vertical transistor. For example, a gate of the source assist device **140** can at least partially surround the semiconductor material **210** and also at least partially surround the source cap **220**. Thus, the source assist device **140** may have one doped junction and one undoped junction (e.g., instead of two doped junctions or two un-doped junctions as found in a symmetric transistor, such as source select device **120**). In the embodiment illustrated in FIG. 2, the drain select device **130** is also shown as an asymmetric vertical transistor. The source assist device **140** can be separated from the source select device **120** by a virtual (e.g., undoped) junction **250**. The source assist device **140** can be used in one or more bias methods that can improve on/off margins for vertical memory operations, as described subsequently.

[0028] As used herein, a virtual junction may be defined as an undoped source/drain region **250** between the gates of the transistors that is formed by inversion charge via gate bias during operation (as opposed to substitutional doping introduced during manufacture as in a conventional transistor). For example, the source assist device **140** and the source select device **120** both share the same channel (the material can be p-type but it semiconductor material (e.g., p-type,

n-type, undoped). The channel can be a solid material completely filling the entire volume or can be a thin film forming a “hollow” channel. During an erase operation, when maximum junction leakage is desired, the gates of both source select device **120** and the source assist device **140** can be biased together (e.g., concurrently), such as to leverage the doped junction for leakage generation. For example, FIG. 2 illustrates one embodiment for voltages for biasing (e.g., applying voltages to) gates of the string **100** during an erase operation using the source assist device **140**.

[0029] It can be seen that, during the erase operation, the source **126** can be biased at a relatively high voltage (e.g., 20V) while the gates of the source select device **120** and the source assist device **140** can be biased together at an enable voltage (e.g., 16V). The control gates of the memory cells **112** can be biased at a reference voltage (e.g., 0V) while the gate of the drain select device **130** can be biased at the enable voltage (e.g., 16V). These voltages are for purposes of illustration only. The present embodiments are not limited to any particular voltages.

[0030] During a program operation, when it is desired to minimize junction leakage, the gate of the source assist device of a deselected string can be biased at the source **126** bias in order to minimize the off-state leakage on the deselected memory blocks. This can provide an increased operating window on the deselected memory blocks while preserving the isolation capability of the de-biased source select gate **120**. For example, FIG. 2 illustrates one embodiment of voltages for biasing gates of a deselected string **100** during a program operation using the source assist device **140**.

[0031] It can be seen that, during the program operation, the source **126** of the deselected string **100** can be biased at a relatively low voltage (e.g., 2V) while the gate of the source select device **120** of the deselected string **100** can be biased at a disable voltage (e.g., 0V) and the gate of the source assist device **140** of the deselected string **100** can be biased at approximately the same voltage as the source (e.g., 2-4V). The control gate of the memory cell selected to be programmed (and thus the control gate of a memory cell in the deselected string commonly coupled with that control gate) can be biased at a program voltage (e.g., increasing program pulses) in a range of 15-20V while the control gates of the other memory cells in the selected and deselected strings can be biased at a pass voltage V_{pass} . The gate of the drain select device **130** can be biased at a relatively low voltage (e.g., 0V). These voltages are for purposes of illustration only. The present embodiments are not limited to any particular voltages.

[0032] FIG. 3 illustrates a schematic diagram of an embodiment of a string of memory cells **300** that can incorporate a drain assist device **340** (e.g., vertical assist device, assist gate, transistor, etc.). The string **300** can be one of multiple strings of memory cells in a block of memory cells in a memory device, such as a NAND memory device.

[0033] The string of memory cells **300** can include a drain select device **330** in series with the drain assist device **340**. Both the drain select device **330** and the drain assist device **340** may be n-channel transistors coupled between a memory cell **312** at one end of the string of memory cells **300** and a data line **334**. The data line **334** can eventually be coupled to sense circuitry (not shown) for sensing a state of

a selected memory cell **312**. As discussed subsequently with reference to FIG. 4, the drain assist device **340** can be an asymmetric transistor.

[0034] At the other end of the string of memory cells **300**, a source select device **320** may be an n-channel transistor coupled between one of the memory cells **312** and a common source **326**. The common source **326** may comprise, for example, commonly doped semiconductor material and/or other conductive material. The common source **326** can be coupled to a reference voltage V_{ss} (e.g., ground) or a voltage source (e.g., a charge pump circuit not shown).

[0035] Each memory cell **312** can comprise, for example, a floating gate transistor or a charge trap transistor. Each memory cell **312** can be a single level cell (SLC) for storing two bits of data or a multiple level cell (MLC) for storing two or more bits of data.

[0036] The memory cells **312**, the drain select device **330**, the drain assist device **340**, and the source select device **320** can be controlled by signals on their respective control gates. The signals on the control gates of the memory cells **312** can be provided on access lines WL0-WL15. In an embodiment, the control gates of memory cells in a row of memory cells can at least partially form an access line.

[0037] The drain select device **330** and the drain assist device **340** can receive a control signal that controls the drain select device **330** and the drain assist device **340** so that the drain select device **330** and the drain assist device **340** can be used to select or deselect the string **300**. The source select device **320** can receive control signals to substantially control conduction between the string of memory cells **300** and the common source **326**.

[0038] FIG. 4 illustrates a cross-sectional view of an embodiment of a semiconductor pillar of the string of memory cells **300** of FIG. 3 that can extend from a substrate (not shown). Portions (e.g., gates) of the memory cells **312**, source select device **320**, the drain select device **330**, and drain assist device **340** can at least partially surround (e.g., surround or partially surround) a semiconductor material **410**. The semiconductor material **410**, in one embodiment, can comprise a pillar of doped or undoped polysilicon and can be used as a channel for the memory cells **312**, the source select device **320**, the drain select device **330**, and the drain assist device **340**. The memory cells **312**, the source select device **320**, the drain select device **330**, and the drain assist device **340** can thus be associated with the pillar of semiconductor material **410**.

[0039] The pillar of semiconductor material **410** can extend between a source cap **420** (e.g., n+ type polysilicon) and a drain cap **430** (e.g., n+ type polysilicon). The source cap **420** can be in electrical contact with the pillar of semiconductor material **410** and can form a doped (e.g., p-n) junction with the semiconductor material **410**. The drain cap **430** can be in electrical contact with the pillar of semiconductor material **410** and can form a doped (e.g., p-n) junction with the semiconductor material **410**. The source cap **420** can be a source for the pillar of semiconductor material **410** and the drain cap **430** can be a drain for the pillar of semiconductor material **410**. The source cap **420** can be coupled to the common source **326**. The drain cap **430** can be coupled to the data line **334**.

[0040] The drain assist device **340** can be an asymmetric vertical transistor. For example, a gate of the drain assist device **340** can at least partially surround the semiconductor material **410** and also at least partially surround the drain cap

430. Thus, the drain assist device **340** can have one doped junction and one undoped junction (e.g., instead of two undoped junctions, such as found in the drain select device **330**). In the embodiment illustrated in FIG. 4, the source select device **320** is also shown as an asymmetric vertical transistor. The device that connects to the data line or source line are asymmetric whether it is on the source or drain side, normal select device or assist device. In the embodiment of FIG. 3, SGD **330** is a symmetric device where both junctions are undoped in this configuration. SGS **320** is asymmetric since the side that connects to **326** has a doped junction while the other side of the device does not.

[0041] The drain assist device **340** can be separated from the drain select device **330** by a virtual junction **350**. The drain assist device **340** can be used in one or more bias methods that can improve on/off margins for vertical memory operations, as described subsequently.

[0042] During an erase operation, the gates of both drain select device **330** and the drain assist device **340** can be biased together in order to maintain an operating margin for erase condition. For example, FIG. 4 illustrates one embodiment for bias voltages for biasing gates of the string **300** during an erase operation using the drain assist device **340**.

[0043] It can be seen that, during the erase operation, the data line **334** can be biased at an erase voltage (e.g., approximately 20V) while the gates of the drain select device **330** and the drain assist device **340** can be biased at an enable voltage that is slightly less than the erase voltage (e.g., 16V). The control gates of the memory cells **312** can be biased at a reference voltage (e.g., 0V) while the gate of the source select device **320** can be biased at the relatively high enable voltage (e.g., 16V). These voltages are for purposes of illustration only. The present embodiments are not limited to any particular voltages.

[0044] During a sense operation, the gate of the drain assist device **340** of a deselected string can be biased at the data line **334** bias, such as to minimize the off-state leakage on the deselected memory blocks thus increasing the operating window. Proper biasing of the drain assist device **340** can shift the point of the junction leakage to a virtual (e.g., undoped) junction **350** of a pillar **410** associated with the string of memory cells **100**. This can minimize the off-state leakage and improve sensing margins. For example, FIG. 4 illustrates one embodiment for voltages for biasing gates of the string **300** during a sense operation using the drain assist device **340**.

[0045] It can be seen that, during the sense operation, the data line **334** can be biased at a relatively low voltage that can be less than 1V (e.g., 0.5V) while the gate of the drain select device **330** of a deselected string **300** can be biased at a disable voltage (e.g., 0V) and the gate of the drain assist device **340** can be biased at the same voltage as the data line (e.g., 0.5V). The control gate of the selected memory cell to be read (and, thus, the control gate of an unselected memory cell in the deselected string **300** that is commonly coupled to the control gate of the selected memory cell) can be biased at a sense voltage (e.g., 5V) while the control gates of the other memory cells in the string **300** (i.e., memory cells in the deselected string **300** having control gates coupled to control gates of unselected memory cells in the selected string) can be biased at a pass voltage V_{pass} (e.g., 10V). These voltages are for purposes of illustration only. The present embodiments are not limited to any particular voltages.

[0046] FIG. 5 illustrates a schematic diagram of an embodiment of a string of memory cells 500 that can incorporate a drain assist device 541 (e.g., drain assist gate) and a source assist device 540 (e.g., source assist gate). The string 500 can be one of multiple strings of memory cells in a block of memory cells in a memory device, such as a NAND memory device.

[0047] The string of memory cells 500 can include a drain select device 530 in series with the drain assist device 541. Both the drain select device 530 and the drain assist device 541 may be n-channel transistors coupled between a memory cell 512 at one end of the string of memory cells 500 and a data line 534. The data line 534 can eventually be coupled to sense circuitry (not shown) for sensing a state of a selected memory cell 512. As discussed subsequently with reference to FIG. 6, the drain assist device 541 can be an asymmetric transistor.

[0048] The string of memory cells 500 can include a source select device 520 in series with the source assist device 540. Both the source select device 520 and the source assist device 540 may be n-channel transistors coupled between a memory cell 512 at one end of the string of memory cells 500 and a common source 526. As discussed subsequently with reference to FIG. 6, the source assist device 540 can be an asymmetric transistor.

[0049] The common source 526 may comprise, for example, commonly doped semiconductor material and/or other conductive material. The common source 526 can be coupled to a reference voltage V_{ss} (e.g., ground) or a voltage source (e.g., a charge pump circuit not shown).

[0050] Each memory cell 512 can comprise, for example, a floating gate transistor or a charge trap transistor. Each memory cell 512 can be a single level cell (SLC) for storing two bits of data or a multiple level cell (MLC) for storing two or more bits of data.

[0051] The memory cells 512, the drain select device 530, the drain assist device 541, the source select device 520, and the source assist device 540 can be controlled by signals on their respective control gates. The signals on the control gates of the memory cells 512 can be provided on access lines WL0-WL15. In an embodiment, the control gates of memory cells in a row of memory cells can at least partially form an access line.

[0052] The drain select device 530 and the drain assist device 541 can receive a control signal that controls the drain select device 530 and the drain assist device 541 so that the drain select device 530 and the drain assist device 541 can be used to select or deselect the string 500. The source select device 520 and the source assist gate 540 can receive control signals to substantially control conduction between the string of memory cells 500 and the common source 526.

[0053] FIG. 6 illustrates a cross-sectional view of an embodiment of a semiconductor pillar of the string of memory cells 500 of FIG. 5 that can extend from a substrate (not shown). Portions (e.g., gates) of the memory cells 512, source select device 520, the drain select device 530, drain assist device 541, and source assist device 540 can at least partially surround (e.g., surround or partially surround) a semiconductor material 610. The semiconductor material 610, in one embodiment, can comprise a pillar of p-type polysilicon and can be used as a channel for the memory cells 512, the source select device 520, the drain select device 530, the drain assist device 541, and the source assist

device 540. The memory cells 512, the source select device 520, the drain select device 530, the drain assist device 541, and the source assist device 540 can thus be associated with the pillar of semiconductor material 610.

[0054] The pillar of semiconductor material 610 can extend between a source cap 620 (e.g., n+ type polysilicon) and a drain cap 630 (e.g., n+ type polysilicon). The source cap 620 can be in electrical contact with the pillar of semiconductor material 610 and can form a doped (e.g., p-n) junction with the semiconductor material 610. The drain cap 630 can be in electrical contact with the pillar of semiconductor material 610 and can form a doped (e.g., p-n) junction with the semiconductor material 610. The source cap 620 can be a source for the pillar of semiconductor material 610 and the drain cap 630 can be a drain for the pillar of semiconductor material 610. The source cap 620 can be coupled to the common source 526. The drain cap 630 can be coupled to the data line 534.

[0055] The drain assist device 541 and the source assist device 540 can be asymmetric vertical transistors. For example, gates of the drain assist device 541 and the source assist device 540 can at least partially surround the semiconductor material 610 and also at least partially surround their respective caps 630, 620. Thus, the drain assist device 541 and the source assist device 540 can each have one doped junction and one undoped junction (instead of two undoped junctions, as found in each of the drain and source select devices 530, 520). The source and drain assist devices 540, 541 can be separated from their respective select devices 520, 530 by a respective virtual junction 631, 632. The drain assist device 541 and the source assist device 540 can be used in one or more bias methods that can improve on/off margins for vertical memory operations.

[0056] The biasing of the gates of the drain assist device 541 and the source assist device 540 during memory operations are shown previously with reference to FIGS. 2 and 4. For example, during an erase operation the gate of the source assist device 540 can be biased at approximately 16V while the gate of the drain assist device 541 can be biased at approximately 16V. During a sense operation, the gate of the source assist device 540 of a deselected string 500 can be biased at some voltage that is less than 1V (e.g., 0.5V) while the gate of the drain assist device of the deselected string 500 can be biased at approximately the same voltage (e.g., 0.5V). During a program operation, the gate of the source assist device 540 of a deselected string 500 can be biased at approximately 2-4V while the gate of the drain assist device 541 of the deselected string 500 can be biased at approximately 2-4V. As in all previous embodiments, these voltages are for purposes of illustration only as the embodiments are not limited to any one particular voltage.

[0057] FIG. 7 illustrates a cross-sectional view of another embodiment of a semiconductor pillar of a string of memory cells 700 that can extend from a substrate (not shown). This embodiment can include multiple source select devices 720, 721 and a source assist device 722. Portions (e.g., gates) of the memory cells 712, the source select devices 720, 721, the drain select device 731, and the source assist device 722 can at least partially surround (e.g., surround or partially surround) a semiconductor material 710. The semiconductor material 710, in an embodiment, can comprise a pillar of p-type polysilicon and can be used as a channel for the memory cells 712, the source select devices 720, 721, the drain select device 731, and the source assist device 722.

The memory cells **712**, the source select devices **720**, **721**, the drain select device **731**, and the source assist device **722** can thus be associated with the pillar of semiconductor material **710**.

[0058] The pillar of semiconductor material **710** can extend between a source cap **723** (e.g., n+ type polysilicon) and a drain cap **730** (e.g., n+ type polysilicon). The source cap **723** can be in electrical contact with the pillar of semiconductor material **710** and can form a doped (e.g., p-n junction) with the semiconductor material **710**. The drain cap **730** can be in electrical contact with the pillar of semiconductor material **710** and can form a doped (e.g., p-n) junction with the semiconductor material **710**. The source cap **723** can be a source for the pillar of semiconductor material **710** and the drain cap **730** can be a drain for the pillar of semiconductor material **710**. The source cap **723** can be coupled to the common source **724**. The drain cap **730** can be coupled to the data line **734**.

[0059] The source assist device **722** can be an asymmetric vertical transistor. For example, a gate of the source assist device **722** can at least partially surround the semiconductor material **710** and also at least partially surround the source junction **723**. Thus, the asymmetric source assist device **722** can have one doped junction and one undoped junction (e.g., instead of two undoped/virtual junctions, as found in the symmetric source select devices **720**, **721**). In the embodiment illustrated in FIG. 7, the drain select device **731** is also shown as an asymmetric vertical transistor. The biasing of the gates of the source select devices **720**, **721**, the source assist device **722**, the drain select device **731** and the control gates of the memory cells during memory operations were shown and discussed previously.

[0060] FIG. 8 illustrates a cross-sectional view of another embodiment of a semiconductor pillar of a string of memory cells **800** that can extend from a substrate (not shown). This embodiment can include multiple source select devices **820**, **821** and multiple source assist devices **822**, **823**. Portions (e.g., gates) of the memory cells **812**, the source select devices **820**, **821**, the drain select device **831**, and the source assist devices **822**, **823** can at least partially surround (e.g., surround or partially surround) a semiconductor material **810**. The semiconductor material **810**, in an embodiment, can comprise a pillar of p-type polysilicon and can be used as a channel for the memory cells **812**, the source select devices **820**, **821**, the drain select device **831**, and the source assist devices **822**, **823**. The memory cells **812**, the source select devices **820**, **821**, the drain select device **831**, and the source assist devices **822**, **823** can thus be associated with the pillar of semiconductor material **810**.

[0061] The pillar of semiconductor material **810** can extend between a source cap **824** (e.g., n+ type polysilicon) and a drain cap **830** (e.g., n+ type polysilicon). The source cap **824** can be in electrical contact with the pillar of semiconductor material **810** and can form a doped (e.g., p-n) junction with the semiconductor material **810**. The drain cap **830** can be in electrical contact with the pillar of semiconductor material **810** and can form a doped (e.g., p-n) junction with the semiconductor material **810**. The source cap **824** can be a source for the pillar of semiconductor material **810** and the drain cap **830** can be a drain for the pillar of semiconductor material **810**. The source cap **824** can be coupled to the common source **825**. The drain cap **830** can be coupled to the data line **834**.

[0062] One of the source assist devices **823** can be an asymmetric vertical transistor while the other source assist device **822** can be a symmetric vertical transistor. For example, a gate of the asymmetric source assist device **823** can at least partially surround the semiconductor material **810** and also at least partially surround the source cap **824**. Thus, the asymmetric source assist device **823** can have one doped junction and one undoped junction (e.g., instead of two undoped junctions, as found in each of the source select devices **820**, **821** and the other source assist device **822**). In the embodiment illustrated in FIG. 8, the drain select device **831** is also shown as an asymmetric vertical transistor. The biasing of the gates of the source select devices **820**, **821**, the source assist devices **822**, **823**, the drain select device **831** and the control gates of the memory cells during memory operations were shown and discussed previously.

[0063] In the embodiments of FIGS. 7 and 8, the use of multiple select devices may ease process integration for some architectures such that current memory operations can operate with the disclosed embodiments with minimal changes. One device can be designated as an assist device while the gate of the other devices can be biased together as disclosed in the embodiments of FIGS. 2 and/or 4. The designation of which of the devices are to be used as primary select devices and which are assist devices can be determined after manufacture and trimmed to null out variability. The assist device length can be set by a nominal junction depth and its variability introduced during the manufacturing process. The device size can be set by ensuring that a metallurgical junction resides between the edges of the polysilicon control gate.

[0064] While the embodiments of FIGS. 7 and 8 illustrate multiple source select devices and multiple select assist devices, other embodiments can employ multiple drain select devices with a single drain assist device, multiple drain select devices with multiple drain assist devices, or any combination of the above described embodiments.

[0065] FIG. 9 illustrates diagrams of examples of junction voltage differences during memory operations in accordance with the embodiment of FIGS. 1 and 2. FIG. 9 illustrates a portion **950**, **952** of the pillar structure of FIG. 2. The top structure **950** is shown biased as in an erase operation while the bottom structure **952** is shown biased as in a program operation.

[0066] The junction voltage diagram **951** of the erase operation shows that, when high leakage is desired (e.g., erase operation), the gate of the source assist device **901** (SAD) can be biased substantially similarly to the gate of the select device **900** (SSD) (e.g., 16V) so that the larger voltage drop can be shifted from the virtual junction **911** to the doped junction **910** (e.g., the junction between the doped N+ source cap and the pillar material). The virtual junction **911**, at the intersection of the select device and the assist device, can have a smaller voltage drop.

[0067] The junction voltage diagram **953** of the program operation shows that, when low leakage is desired (e.g., program operation), the gate of the assist device **901** of a deselected string can be biased to shift the larger voltage drop to the virtual junction **931**. The junction **930** (e.g., the junction between the doped N+ source cap and the pillar material) can have a smaller voltage drop. A junction electric field diagram **954** for the program operation illustrates an embodiment of the select device/assist device junction being biased to minimize the maximum electric field.

[0068] The diagrams of FIG. 9 illustrate the junction voltage between source assist device and the source select device. The junction voltage shift between the drain assist device and the drain select device is substantially similar.

[0069] FIG. 10 illustrates a block diagram of an apparatus that may use the vertical assist devices of FIGS. 1-8. A controller 1000 may be used to control operations of the apparatus. A memory device 1001, coupled to the controller 1000, may include a memory array comprising memory cell strings with vertical assist devices as described above with reference to FIGS. 1-8.

[0070] In an embodiment, the controller 1000 may be coupled to the memory device 1001 over control, data, and address buses. In another embodiment, the address and data buses may share a common input/output (I/O) bus. The controller 1000 can be part of the same integrated circuit as the memory device 1001 or as separate integrated circuits.

[0071] As used herein, an apparatus may refer to, for example, circuitry, an integrated circuit die, a memory device, a memory array, or a system including such a circuit, die, device or array.

CONCLUSION

[0072] One or more embodiments of the vertical assist device can increase on/off margins when biased to shift the largest voltage drop from a doped junction between the source or drain and the pillar of semiconductor material to a virtual junction between the assist device and the select device during an operation that desires high leakage. During an operation that desires low leakage, the gate of an assist device can be biased to shift the largest voltage drop to the virtual junction between the assist device and the select device.

[0073] Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement that is calculated to achieve the same purpose may be substituted for the specific embodiments shown. Many adaptations will be apparent to those of ordinary skill in the art. Accordingly, this application is intended to cover any adaptations or variations.

What is claimed is:

1. An apparatus, comprising:

a string of vertically arranged memory cells at least partially extending around a semiconductor pillar;

first and second select devices at least partially extending around the semiconductor pillar, the first and second select devices on opposite sides of the memory cells;

first and second assist devices extending at least partially around the semiconductor pillar, the first assist device on the opposite side of the first select device from the memory cells and the second assist device on the opposite side of the second select device from the memory cells; and

a controller configured to control the first and second select devices and the first and second assist devices.

2. The apparatus of claim 1, comprising:

a data line connection opposite the first assist device from the first select device, wherein the data line connection is configured to electrically connect the first assist device to a data line; and

a source line connection opposite the second assist device from the second select device, wherein the source line

connection is configured to electrically connect the second assist device to a source line.

3. The apparatus of claim 1, wherein the controller is configured to bias gates of the first select device and the first assist device to a first voltage during an erase operation, and to bias the gates of the first select device and the first assist device to different second and third voltages during a program operation.

4. The apparatus of claim 3, wherein the controller is configured to bias the gates of the first select device and the first assist device to different second and third voltages during the program operation to reduce junction leakage in contrast to junction leakage during the erase operation, and wherein the first voltage is higher than the second and third voltages, and the third voltage is higher than the second voltage.

5. The apparatus of claim 1, wherein the first select device comprises a symmetric device having a first undoped junction and a second undoped junction,

wherein the first assist device comprises an asymmetric device having a first undoped junction and a second doped junction, and

wherein the second undoped junction of the first select device is coupled to the first undoped junction of the first assist device.

6. The apparatus of claim 5, wherein the second undoped junction of the first select device is directly coupled to the first undoped junction of the asymmetric device.

7. The apparatus of claim 1, wherein the semiconductor pillar extends from a substrate, and wherein the semiconductor pillar is a channel for the string of memory cells, the first and second select devices, and the first and second assist devices.

8. A method, comprising:

controlling, using a controller, first and second select devices and first and second assist devices, the first and second select devices on opposite sides of a string of vertically arranged memory cells at least partially extending around a semiconductor pillar,

wherein the first and second select devices and the first and second assist devices extend at least partially around the semiconductor pillar, and

wherein the first assist device is on an opposite side of the first select device from the memory cells and the second assist device is on an opposite side of the second select device from the memory cells.

9. The method of claim 8, wherein controlling the first and second select devices and the first and second assist devices comprises:

biasing gates of the first select device and the first assist device to a first voltage during an erase operation; and biasing the gates of the first select device and the first assist device to different second and third voltages during a program operation.

10. The method of claim 9, wherein biasing the gates of the first select device and the first assist device to different second and third voltages during the program operation reduces junction leakage in contrast to junction leakage during the erase operation, and

wherein the first voltage is higher than the second and third voltages, and the third voltage is higher than the second voltage.

11. An apparatus, comprising:
 a string of vertically arranged memory cells at least partially extending around a semiconductor pillar;
 a select device at least partially extending around the semiconductor pillar;
 first and second assist devices extending at least partially around the semiconductor pillar, the first and second assist devices on the opposite side of the select device from the memory cells; and
 a controller configured to control the select device and the assist device.

12. The apparatus of claim **11**, comprising:
 a data line connection opposite the first assist device from the select device, wherein the data line connection is configured to electrically connect the first assist device to a data line.

13. The apparatus of claim **11**, comprising:
 a source line connection opposite the first assist device from the select device, wherein the source line connection is configured to electrically connect the first assist device to a source line.

14. The apparatus of claim **11**, wherein the controller is configured to bias gates of the select device and the first assist device to a first voltage during an erase operation, and to bias the gates of the select device and the first assist device to different second and third voltages during a program operation.

15. The apparatus of claim **14**, wherein the controller is configured to bias the gates of the select device and the first assist device to different second and third voltages during the program operation to reduce junction leakage in contrast to junction leakage during the erase operation, and

wherein the first voltage is higher than the second and third voltages, and the third voltage is higher than the second voltage.

16. The apparatus of claim **11**, wherein the select device comprises a symmetric device having a first undoped junction and a second undoped junction,

wherein the first assist device comprises an asymmetric device having a first undoped junction and a second doped junction,

wherein the second assist device comprises a symmetric device having a first undoped junction and a second undoped junction,

wherein the second undoped junction of the select device is coupled to the first undoped junction of the second assist device, and

wherein the second undoped junction of the second assist device is coupled to the first undoped junction of the first assist device.

17. The apparatus of claim **16**, wherein the second undoped junction of the select device is directly coupled to the first undoped junction of the second assist device, and wherein the second undoped junction of the second assist device is directly coupled to the first undoped junction of the first assist device.

18. The apparatus of claim **11**, wherein the semiconductor pillar extends from a substrate, and wherein the semiconductor pillar is a channel for the string of memory cells, the select device, and the first and second assist devices.

19. A method, comprising:

controlling, using a controller, a select device and first and second assist devices, the first and second assist devices on an opposite side of a string of vertically arranged memory cells at least partially extending around a semiconductor pillar,

wherein the select device and the first and second assist devices extend at least partially around the semiconductor pillar, and

wherein the first and second assist devices are on an opposite side of the select device from the memory cells.

20. The method of claim **19**, wherein controlling the select device and the first and second assist devices comprises:

biasing gates of the select device and the first assist device to a first voltage during an erase operation; and

biasing the gates of the select device and the first assist device to different second and third voltages during a program operation to reduce junction leakage in contrast to junction leakage during the erase operation,

wherein the first voltage is higher than the second and third voltages, and the third voltage is higher than the second voltage.

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