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Ryu

(10) **Patent No.:** **US 11,923,416 B2**
(45) **Date of Patent:** **Mar. 5, 2024**

(54) **SEMICONDUCTOR DEVICE HAVING BURIED GATE STRUCTURE AND METHOD FOR FABRICATING THE SAME**

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(73) Assignee: **SK hynix Inc.**, Gyeonggi-do (KR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **17/829,581**

(22) Filed: **Jun. 1, 2022**

(65) **Prior Publication Data**
US 2022/0293734 A1 Sep. 15, 2022

Related U.S. Application Data
(63) Continuation of application No. 16/919,368, filed on Jul. 2, 2020, now Pat. No. 11,380,761, which is a (Continued)

(30) **Foreign Application Priority Data**
Feb. 22, 2018 (KR) 10-2018-0021240

(51) **Int. Cl.**
H01L 29/78 (2006.01)
H01L 21/324 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC **H01L 29/0873** (2013.01); **H01L 21/324** (2013.01); **H01L 29/4236** (2013.01); **H01L 29/66734** (2013.01); **H01L 29/7813** (2013.01)

(58) **Field of Classification Search**
CPC H01L 29/4236; H01L 29/7813; H01L 29/0873; H01L 29/66734; H01L 21/324
See application file for complete search history.

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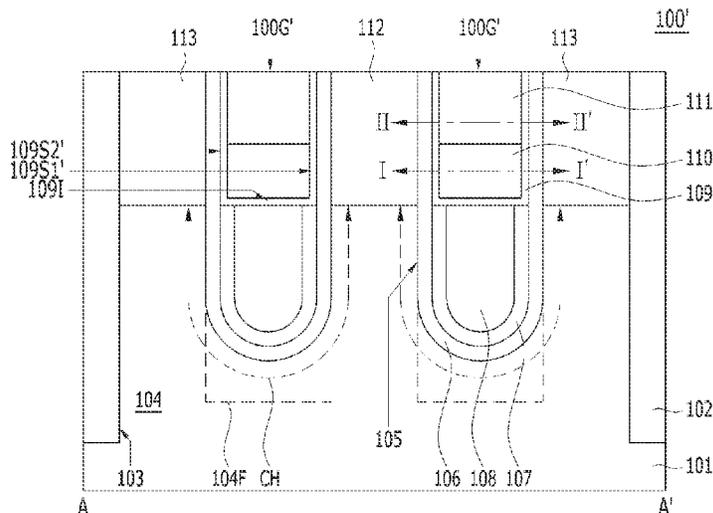
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(57) **ABSTRACT**

A semiconductor device includes: a substrate; a first source/drain region and a second source/drain region spaced apart from each other by a trench in the substrate; and a gate structure in the trench, wherein the gate structure includes: a gate dielectric layer formed on a bottom and sidewalls of the trench; a first gate electrode positioned in a bottom portion of the trench over the gate dielectric layer; a second gate electrode positioned over the first gate electrode; and a dipole inducing layer formed between the first gate electrode and the second gate electrode and between sidewalls of the second gate electrode and the gate dielectric layer.

19 Claims, 41 Drawing Sheets



Related U.S. Application Data

continuation of application No. 16/119,424, filed on Aug. 31, 2018, now Pat. No. 10,741,643.

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(51) **Int. Cl.**

H01L 29/08 (2006.01)
H01L 29/423 (2006.01)
H01L 29/66 (2006.01)

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FIG. 1

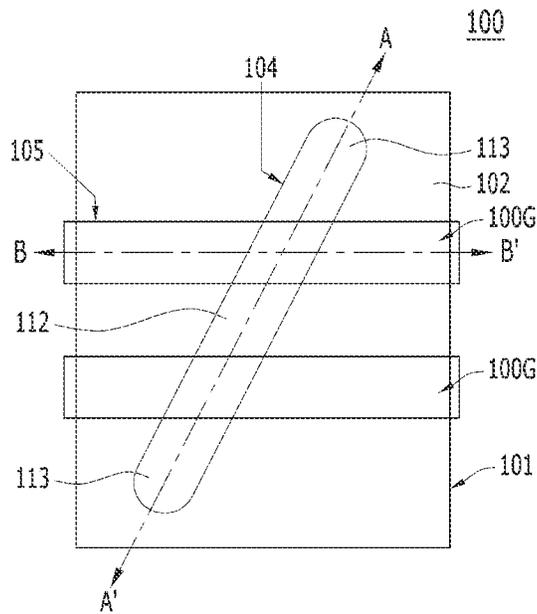


FIG. 2A

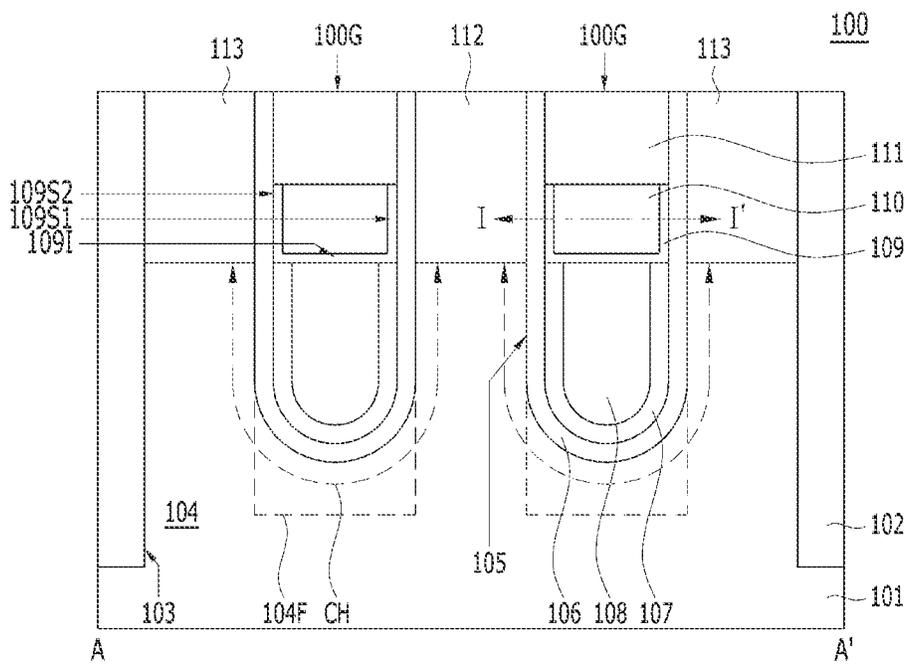


FIG. 2B

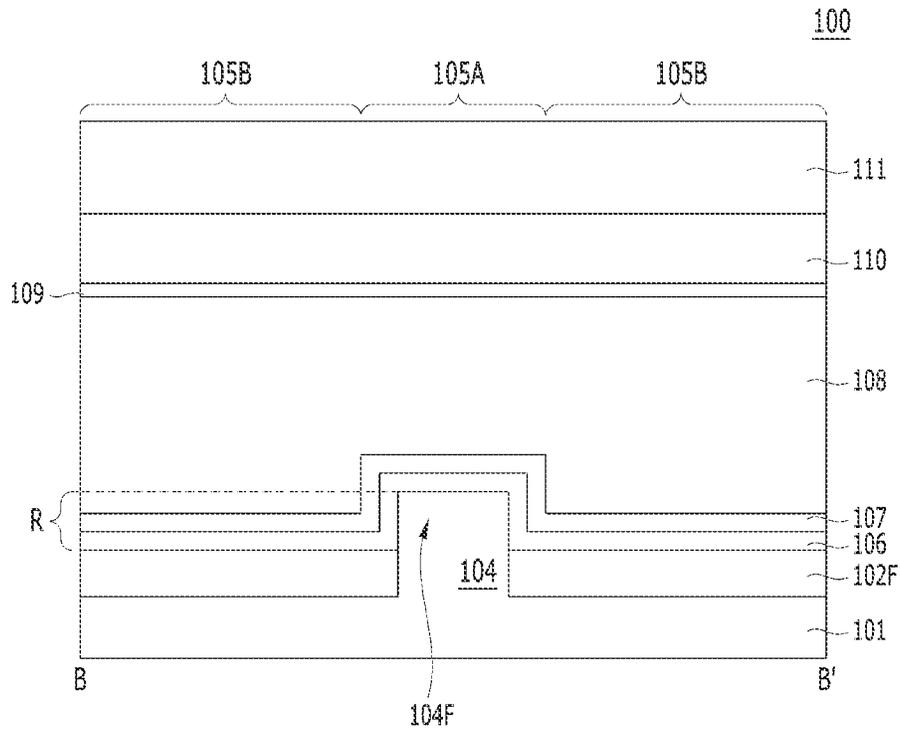


FIG. 3

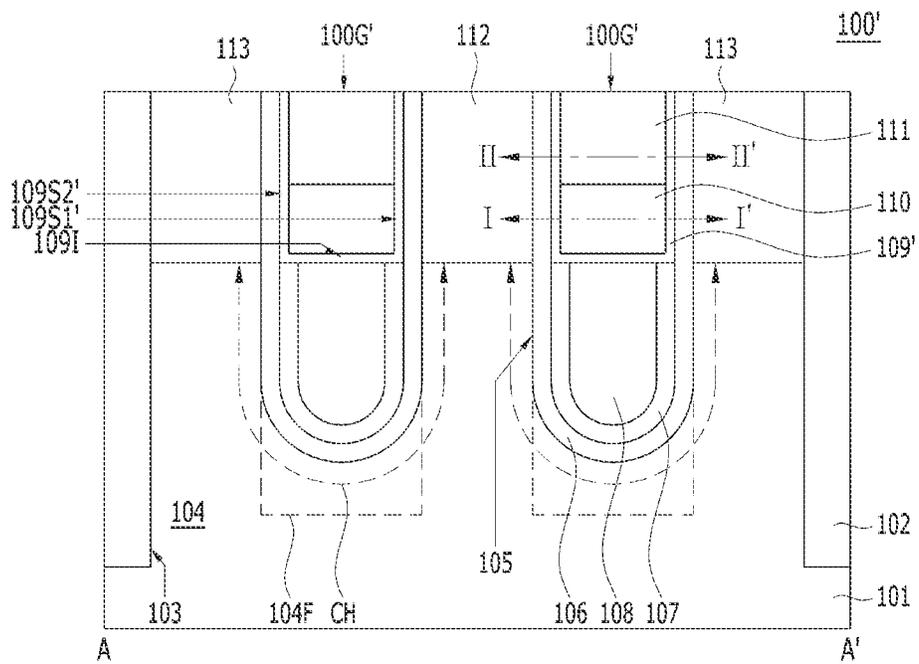


FIG. 4A

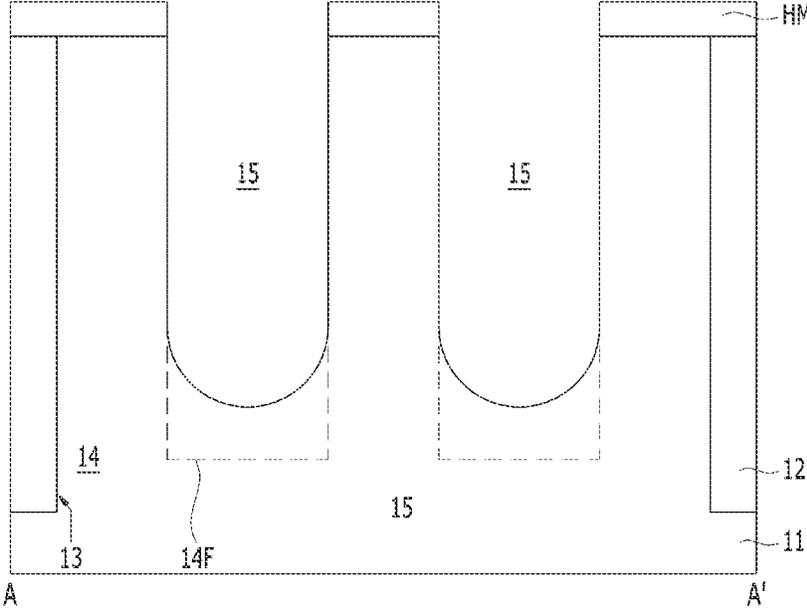


FIG. 4B

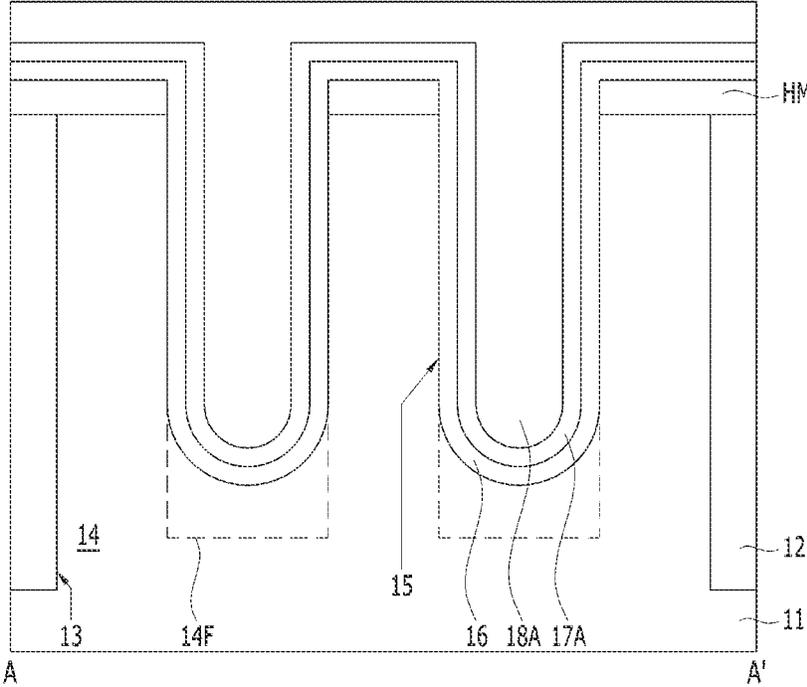


FIG. 4C

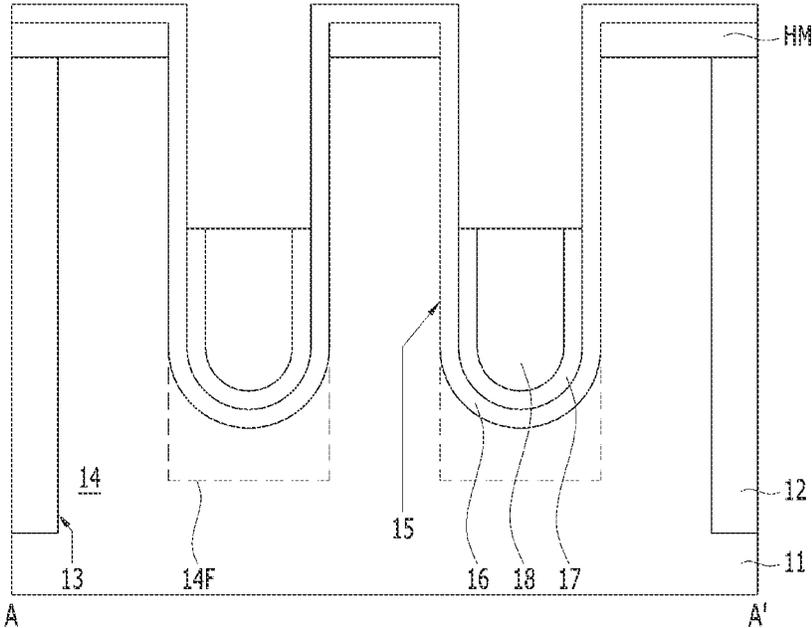


FIG. 4D

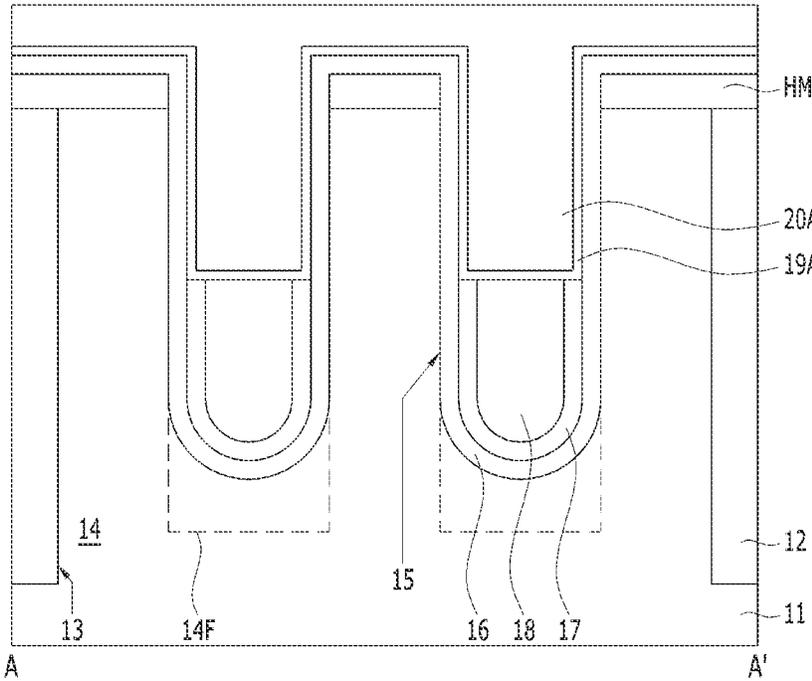


FIG. 4E

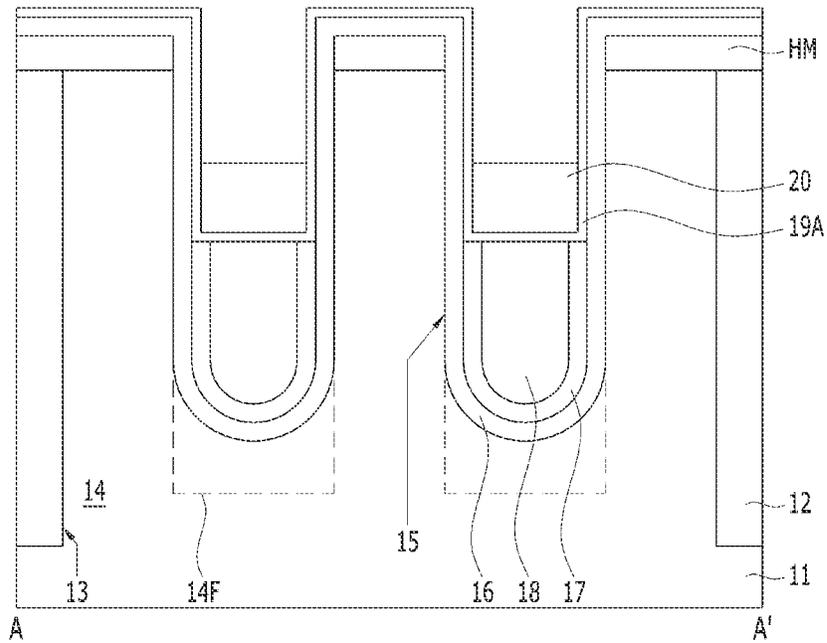


FIG. 4F

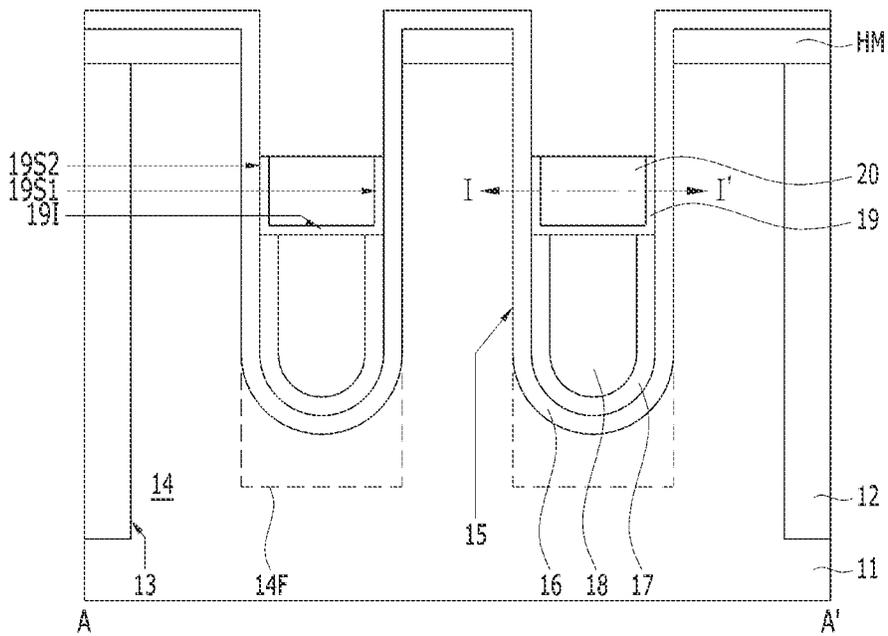


FIG. 4G

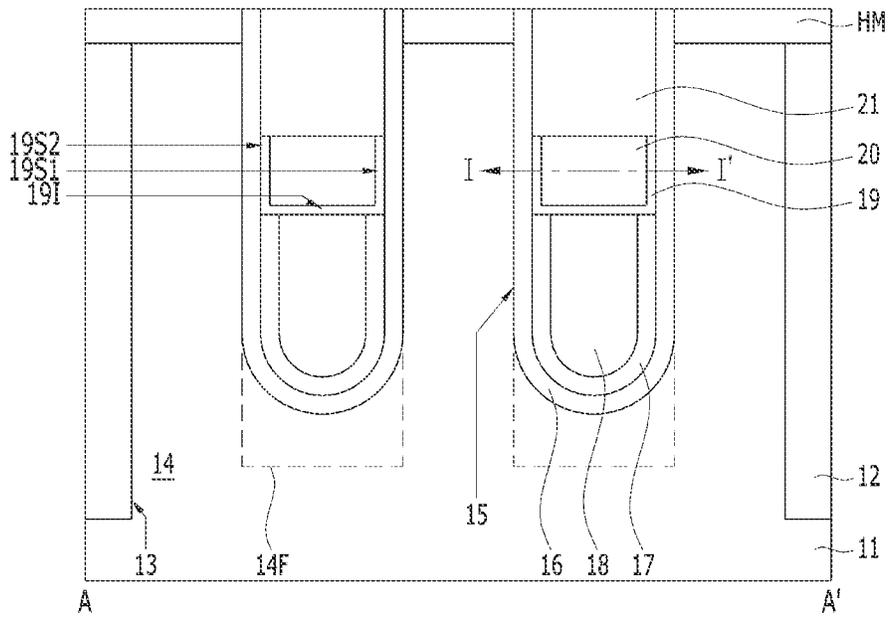


FIG. 4H

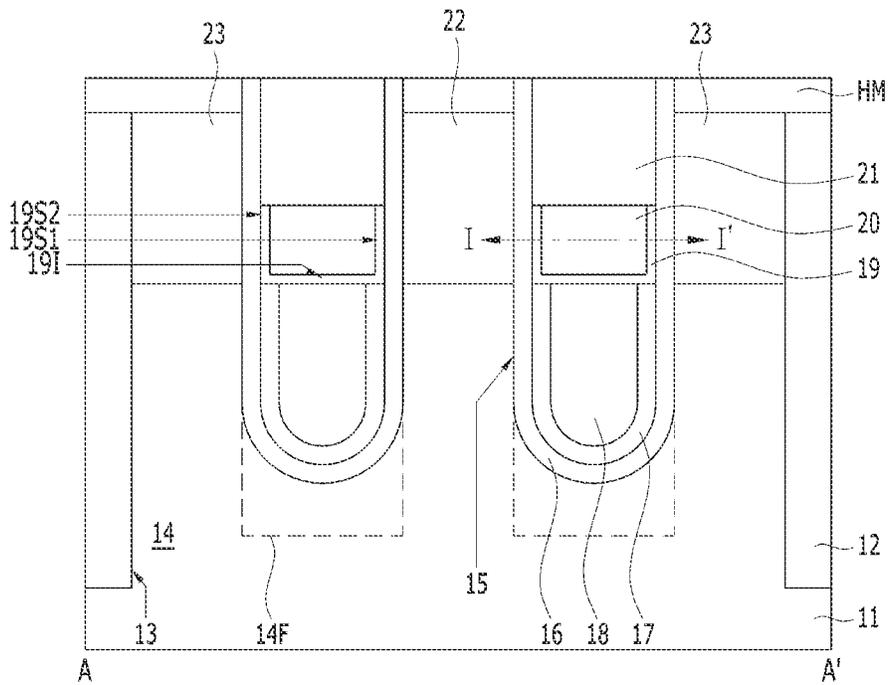


FIG. 5A

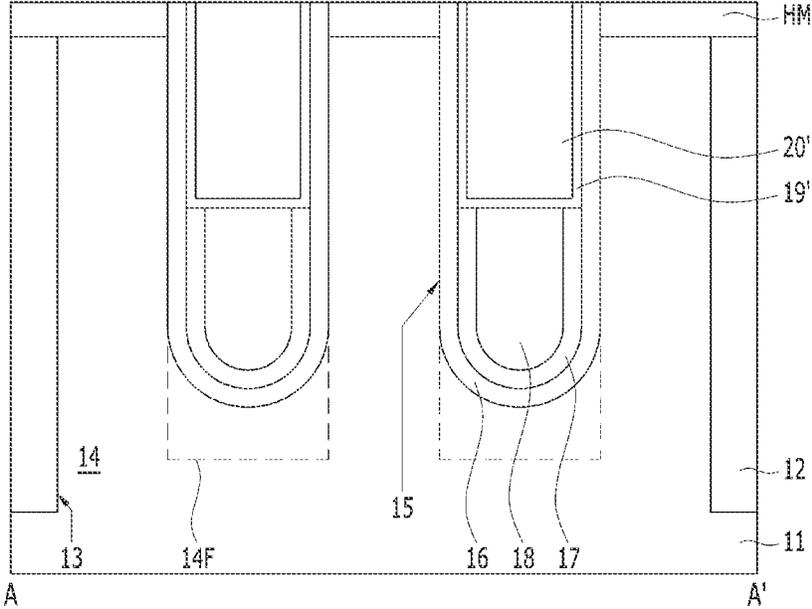


FIG. 5B

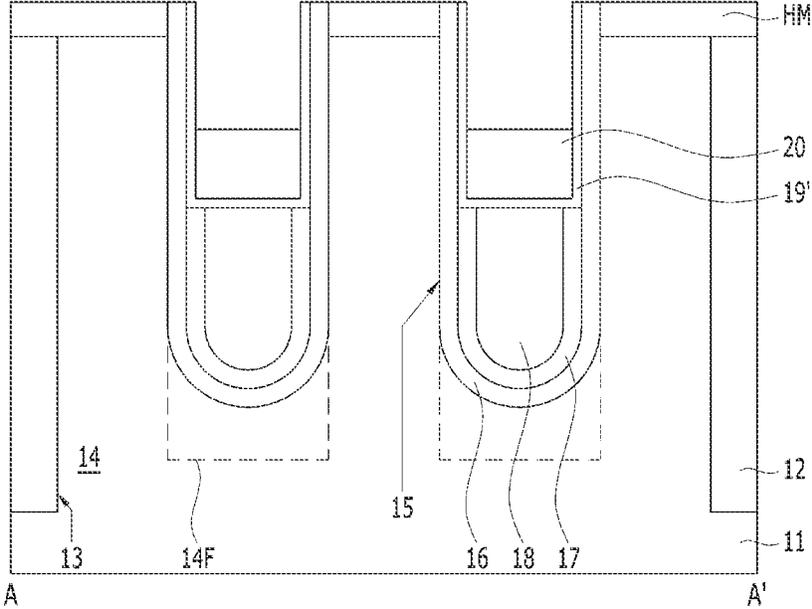


FIG. 5C

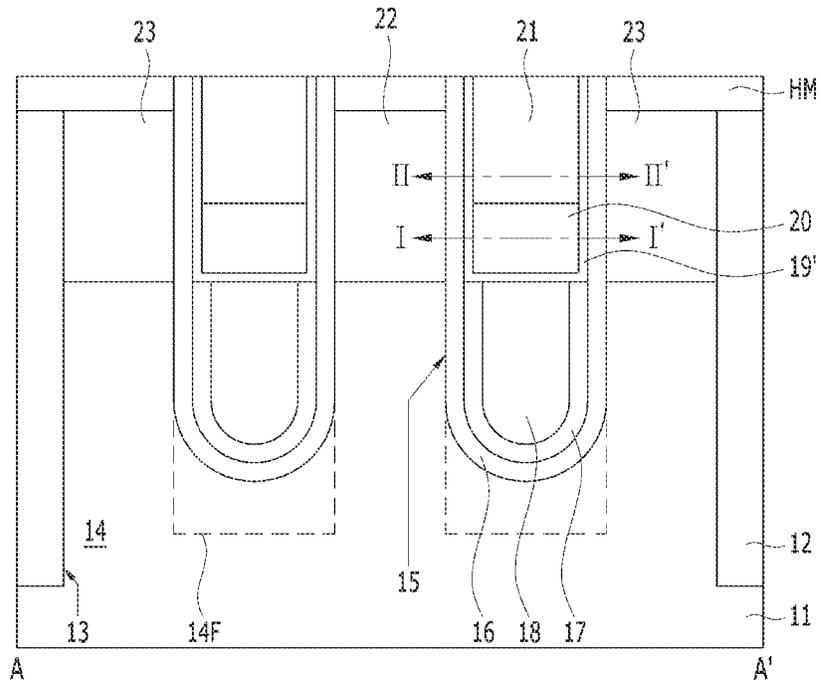


FIG. 6

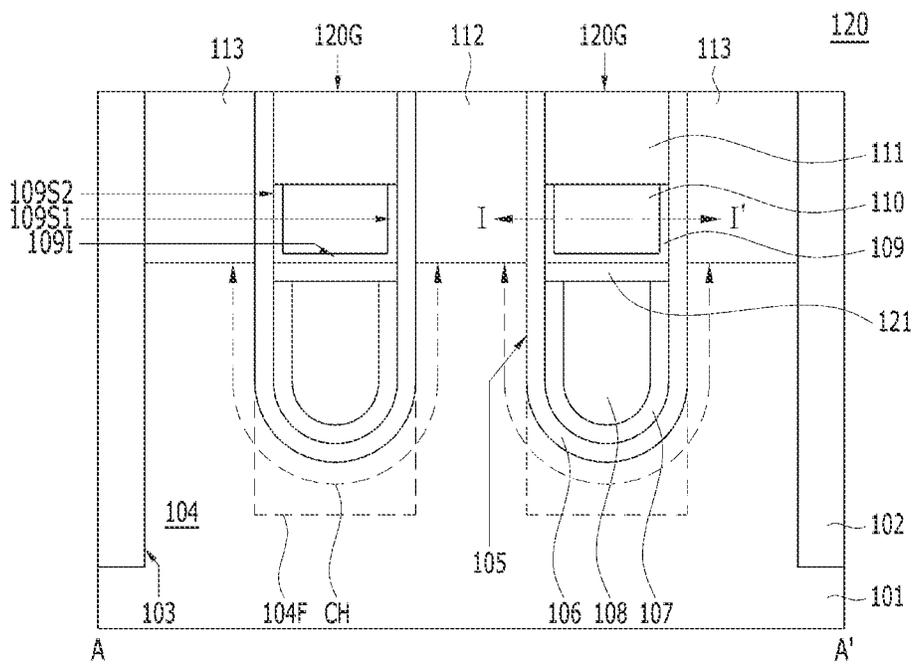


FIG. 7A

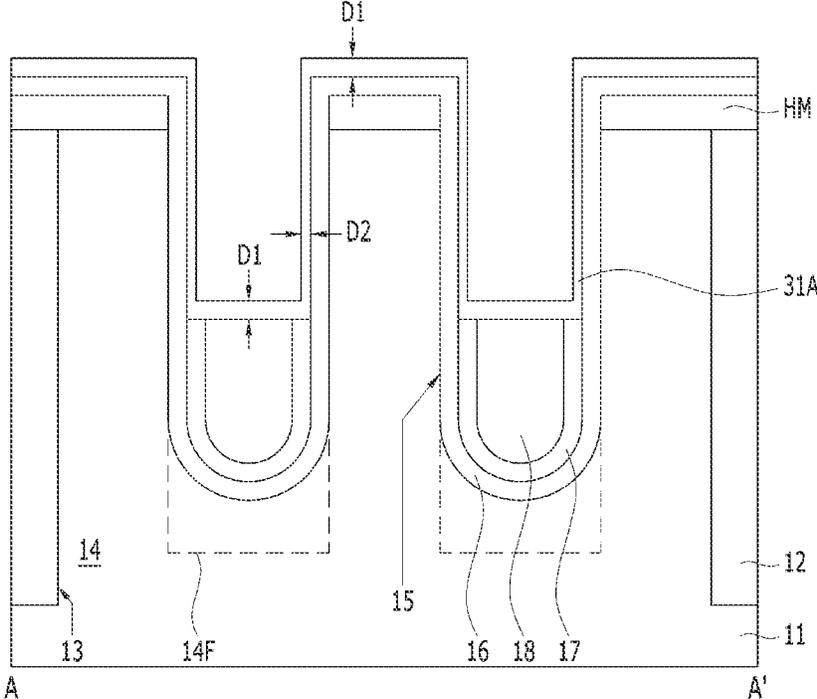


FIG. 7B

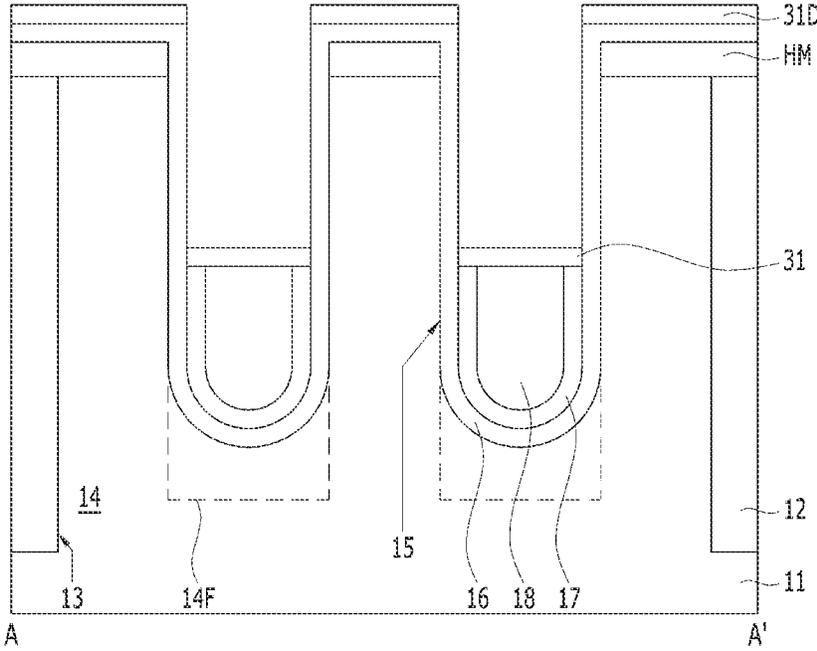


FIG. 7C

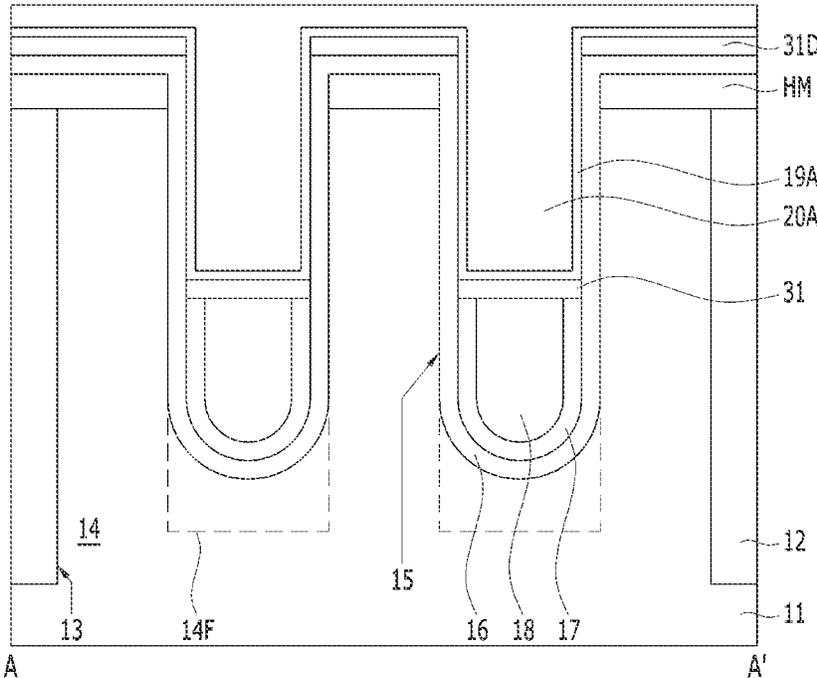


FIG. 7D

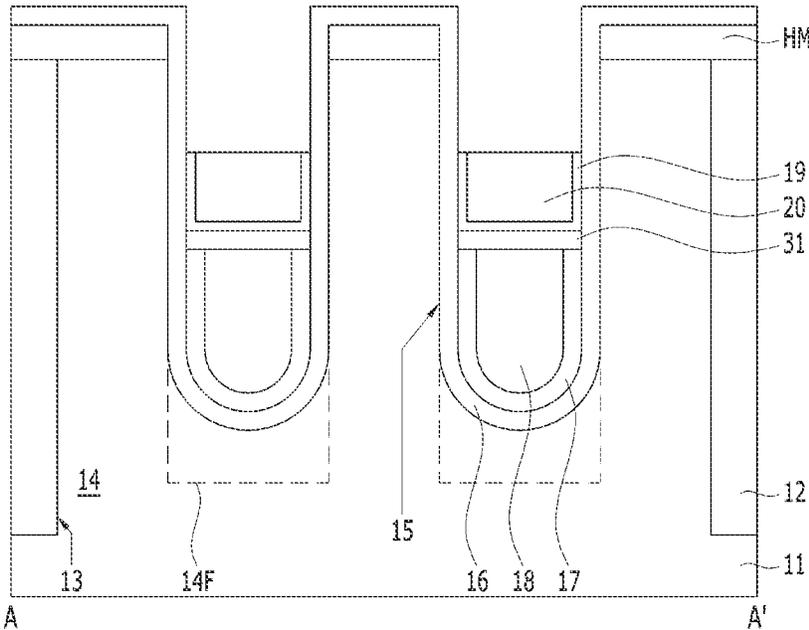


FIG. 7E

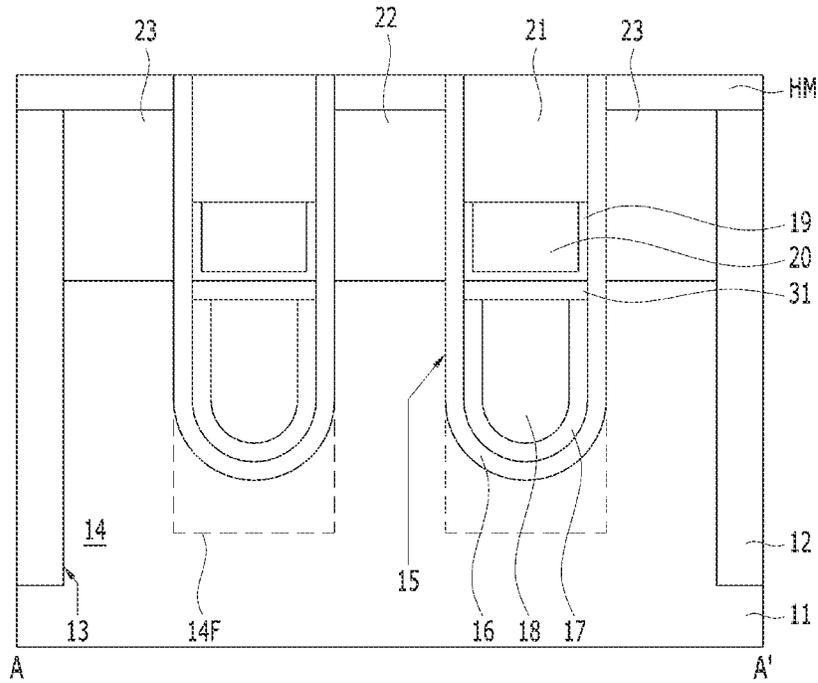


FIG. 8A

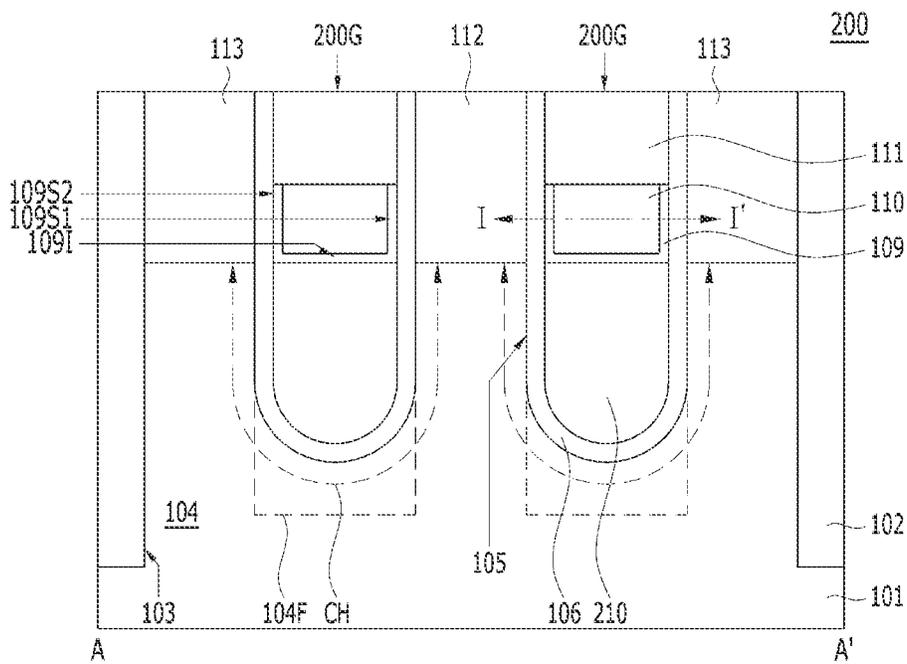


FIG. 9B

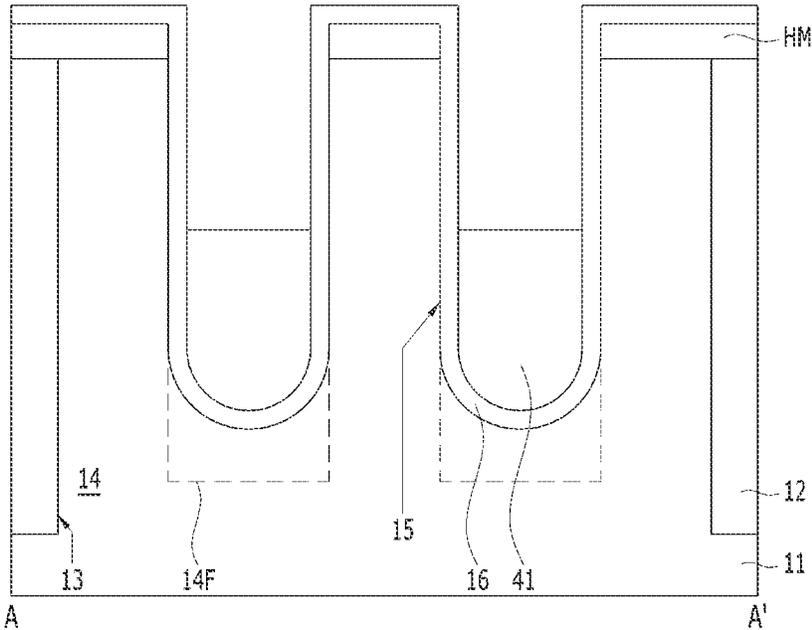


FIG. 9C

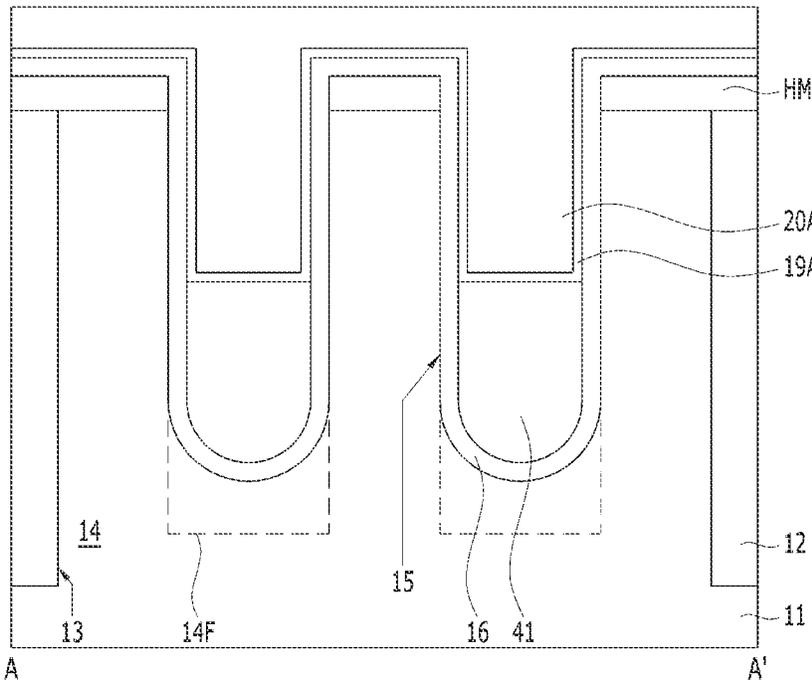


FIG. 9D

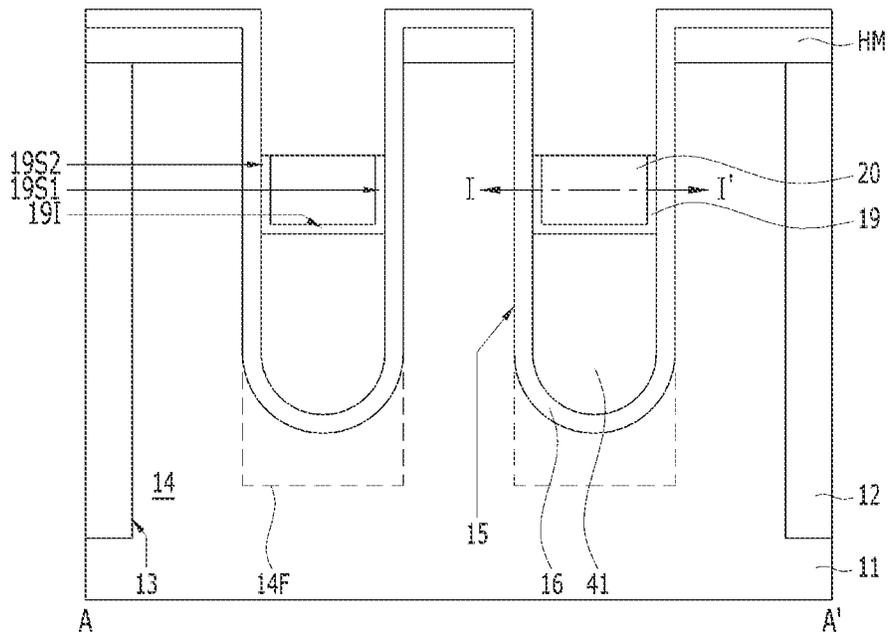


FIG. 9E

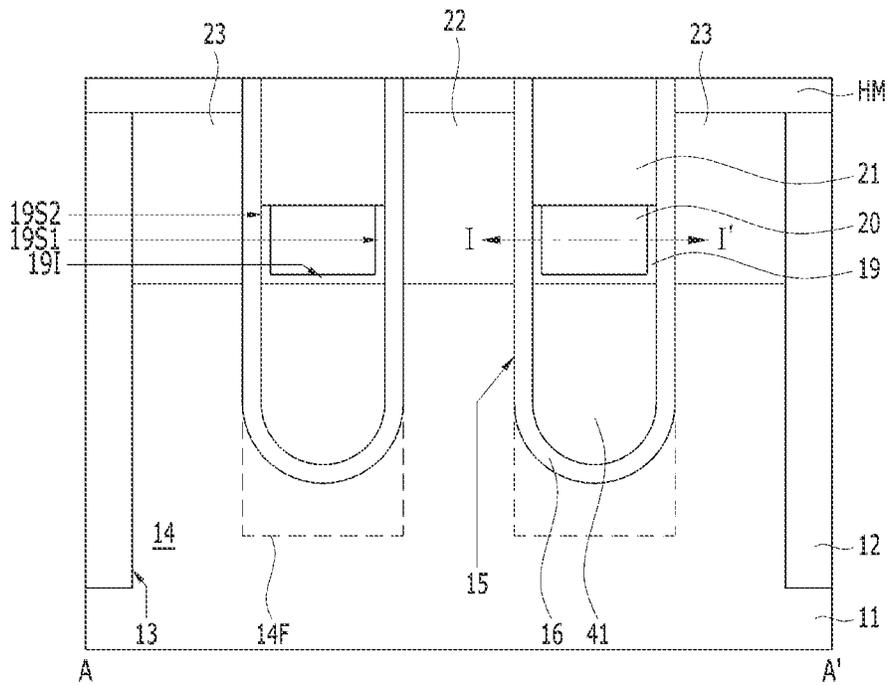


FIG. 10A

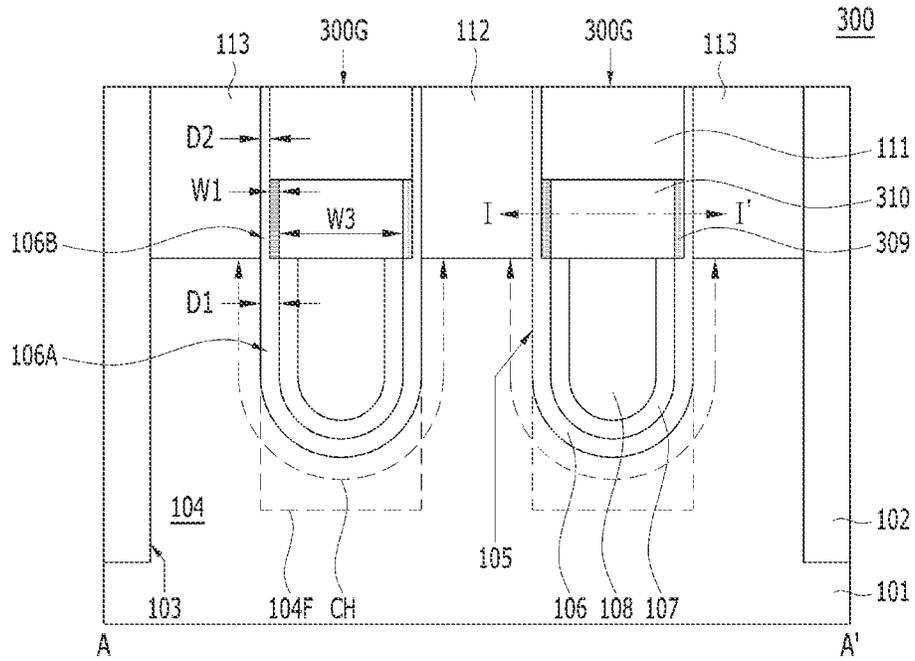


FIG. 10B

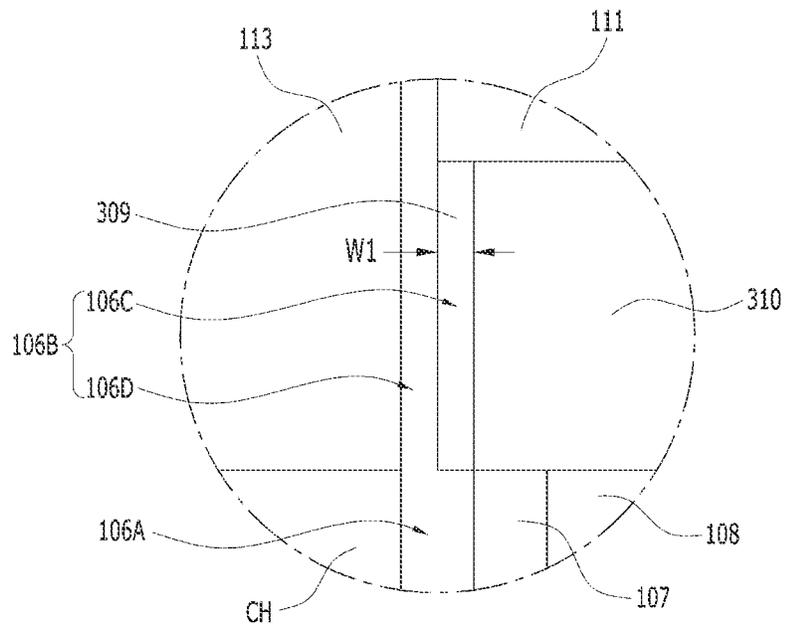


FIG. 11A

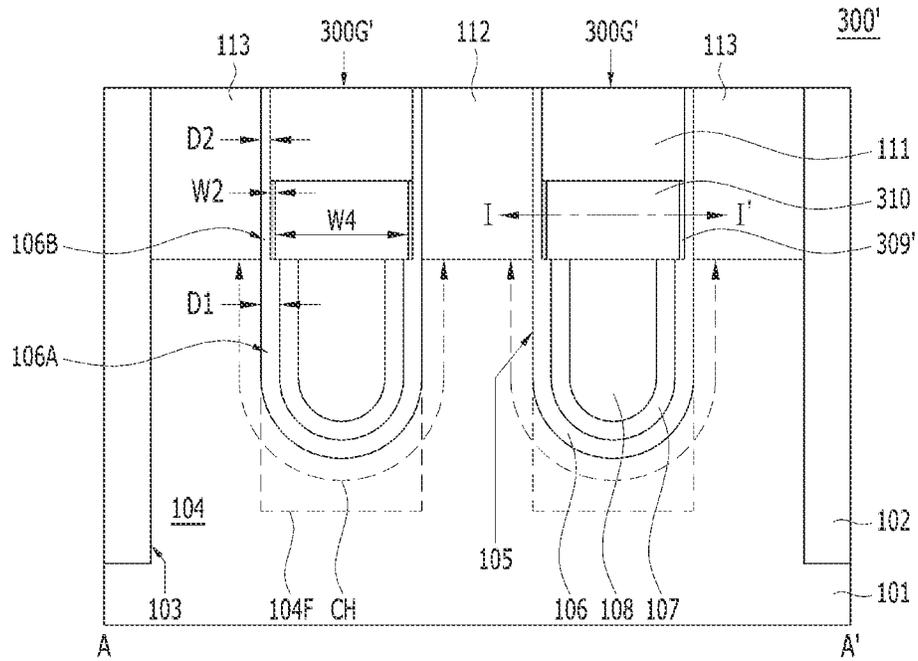


FIG. 11B

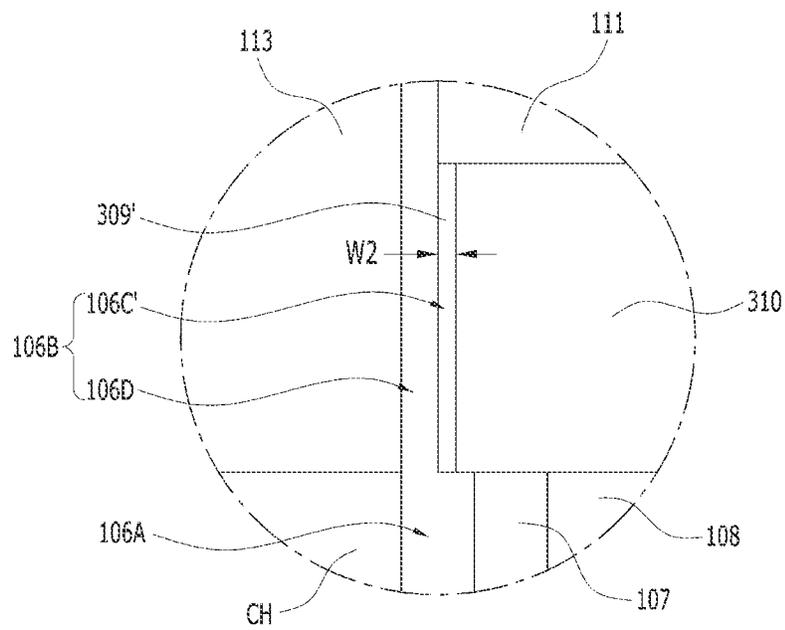


FIG. 12A

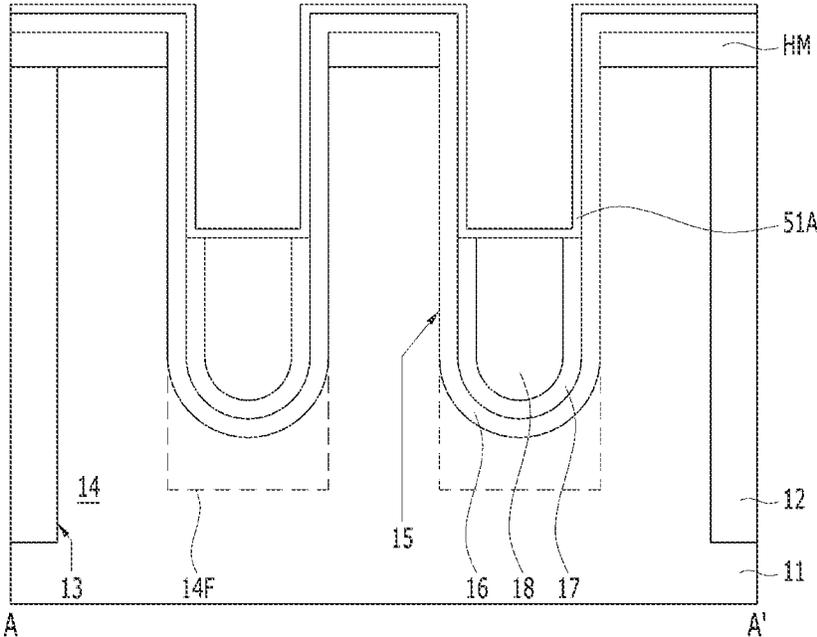


FIG. 12B

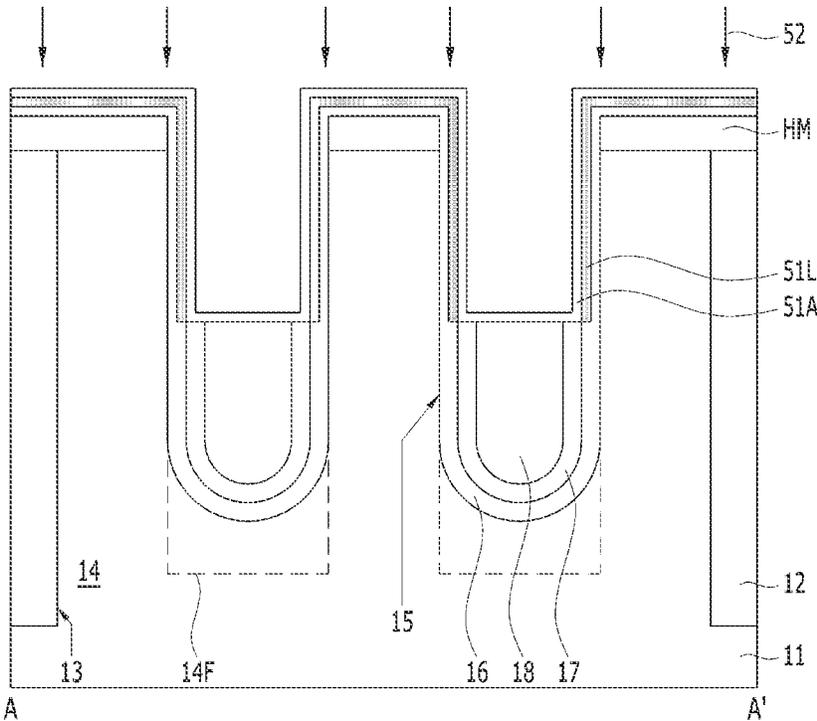


FIG. 12E

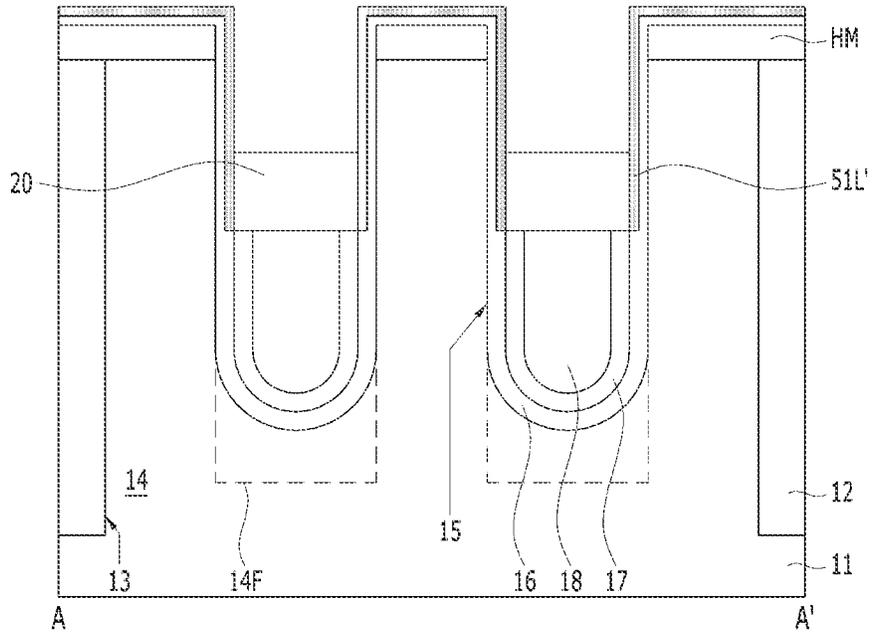


FIG. 12F

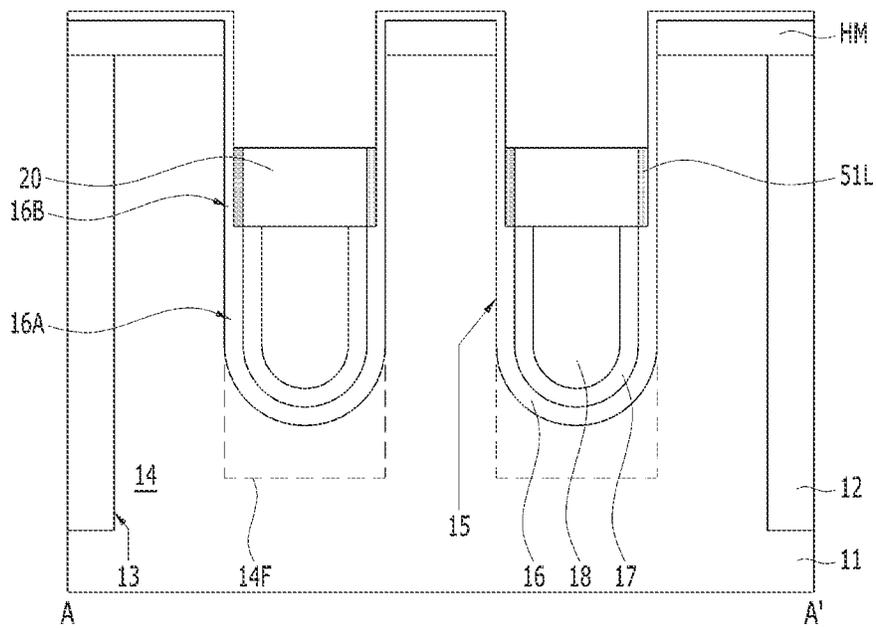


FIG. 13B

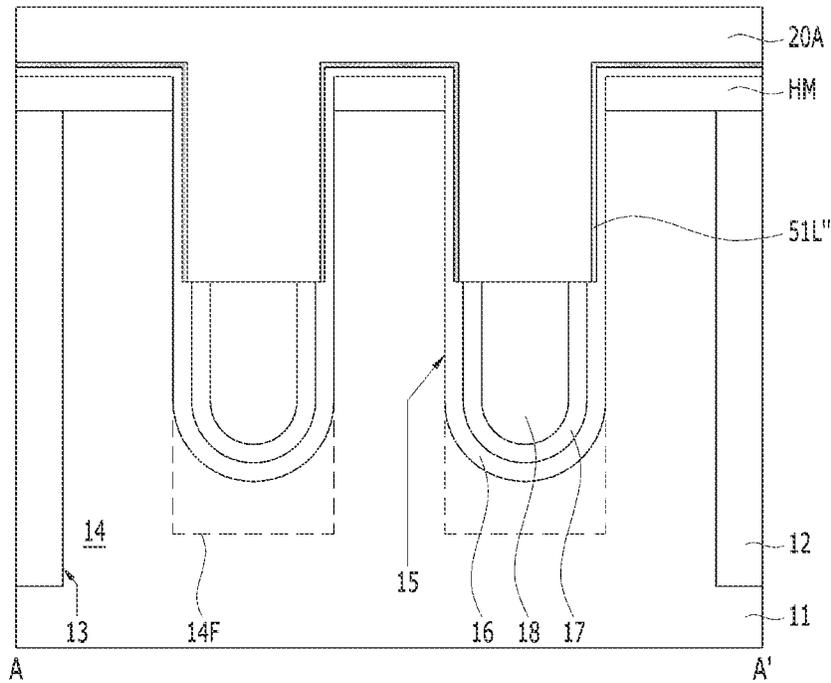


FIG. 13C

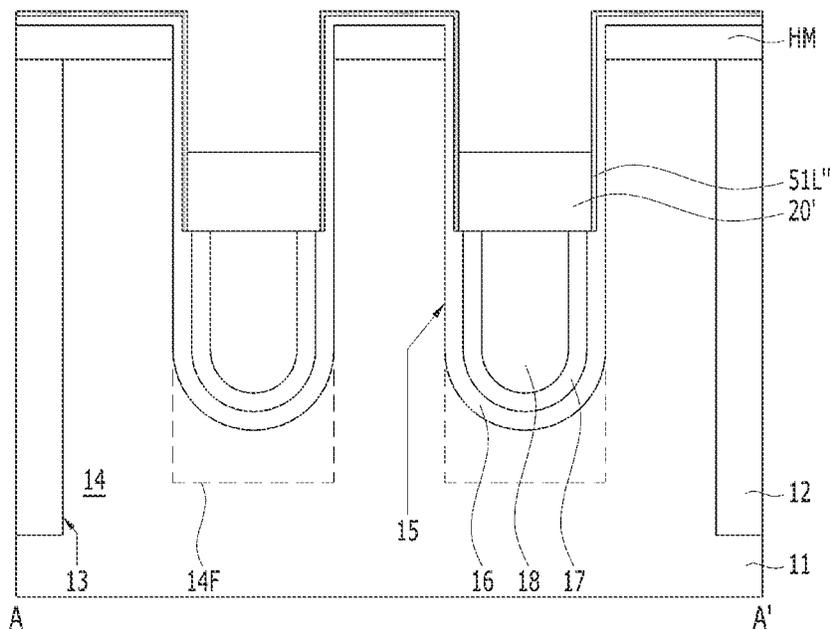


FIG. 13D

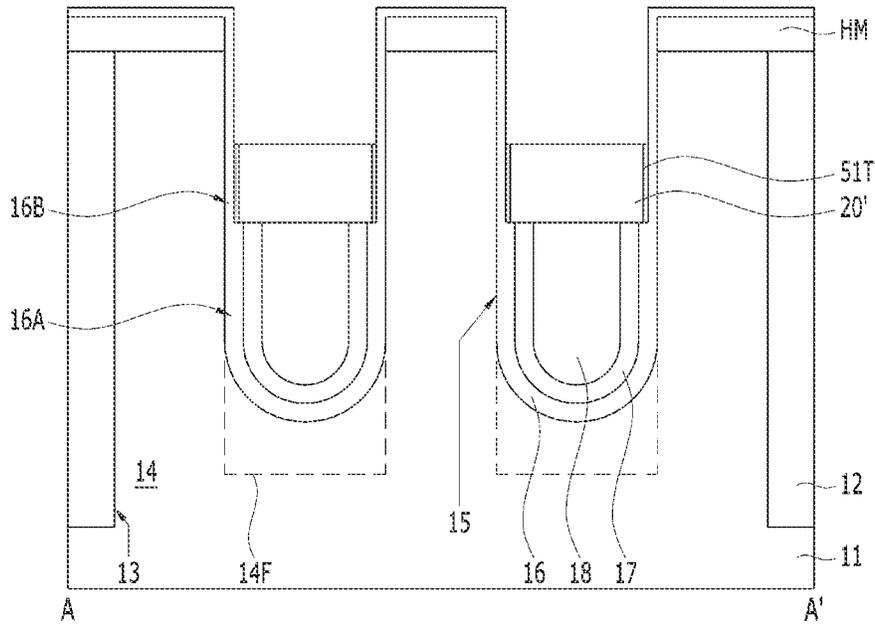


FIG. 13E

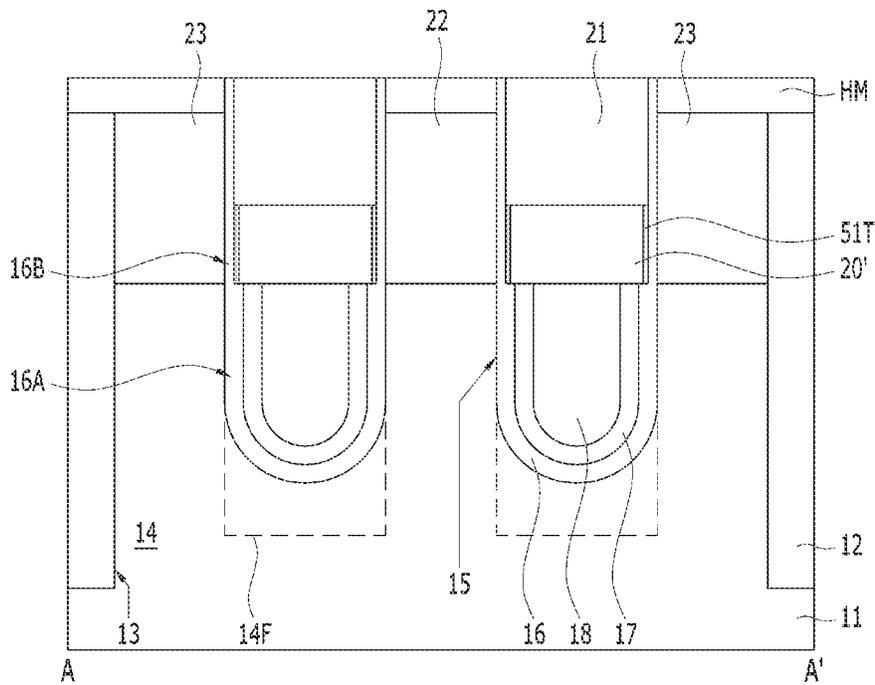


FIG. 14

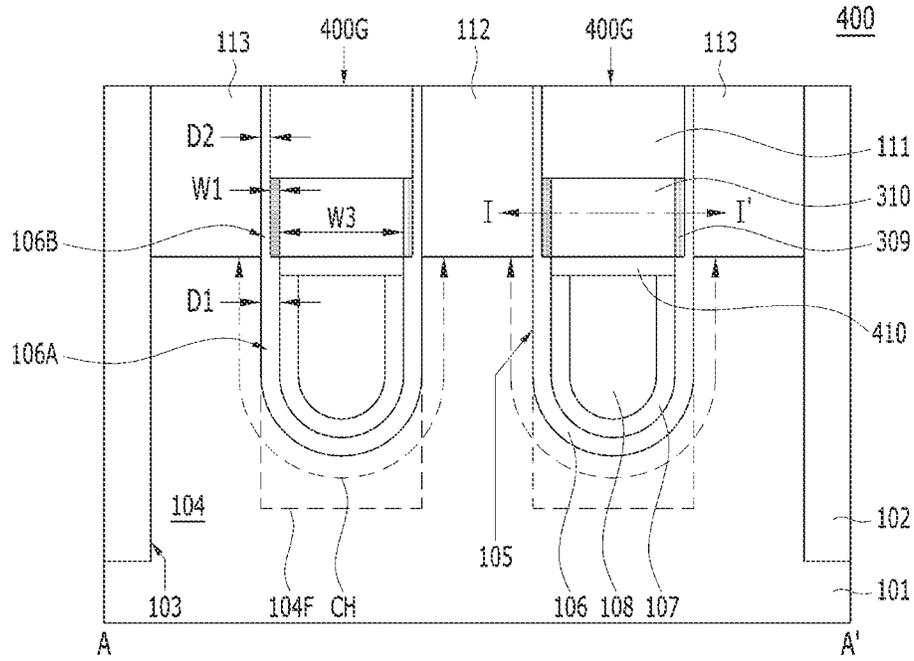


FIG. 15

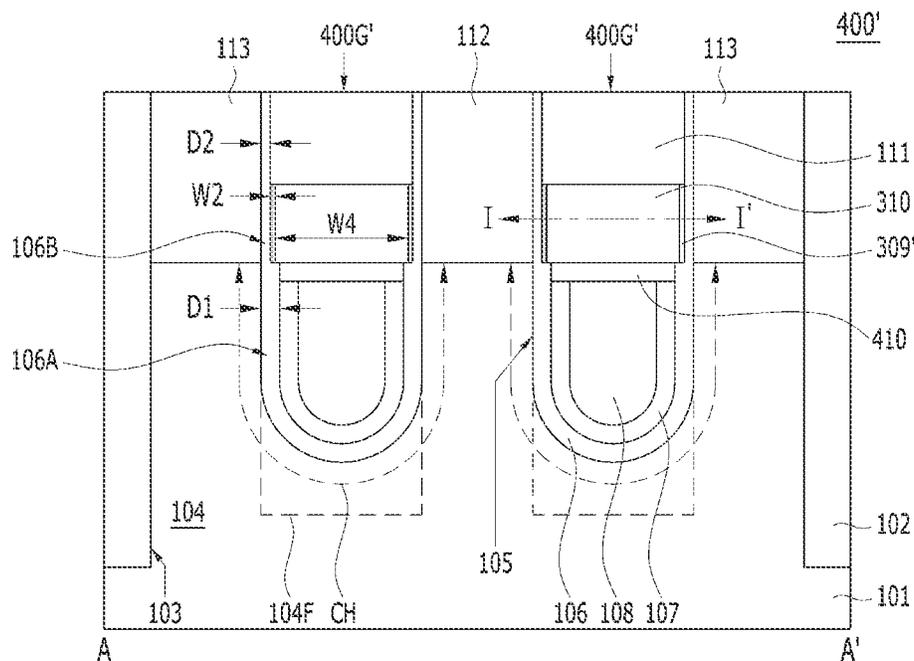


FIG. 16C

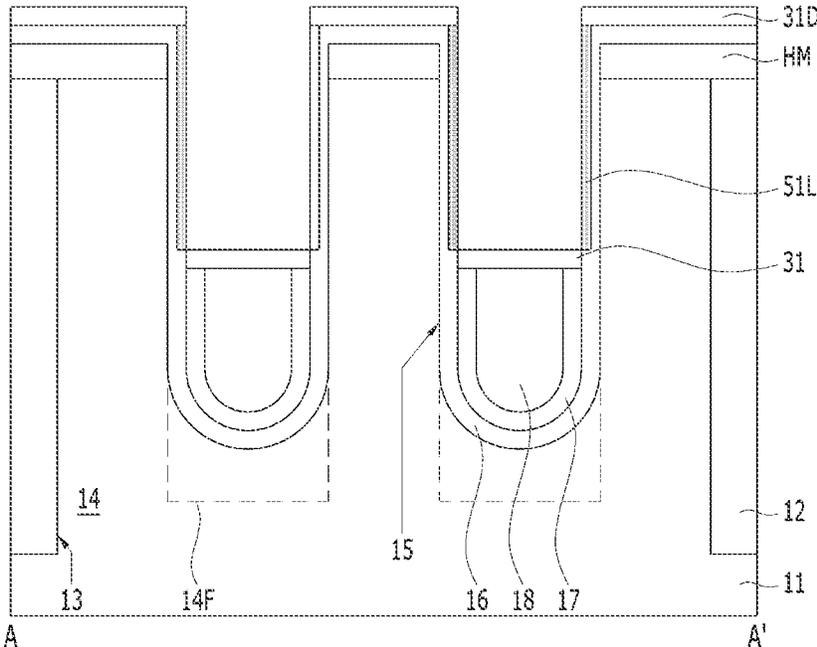


FIG. 16D

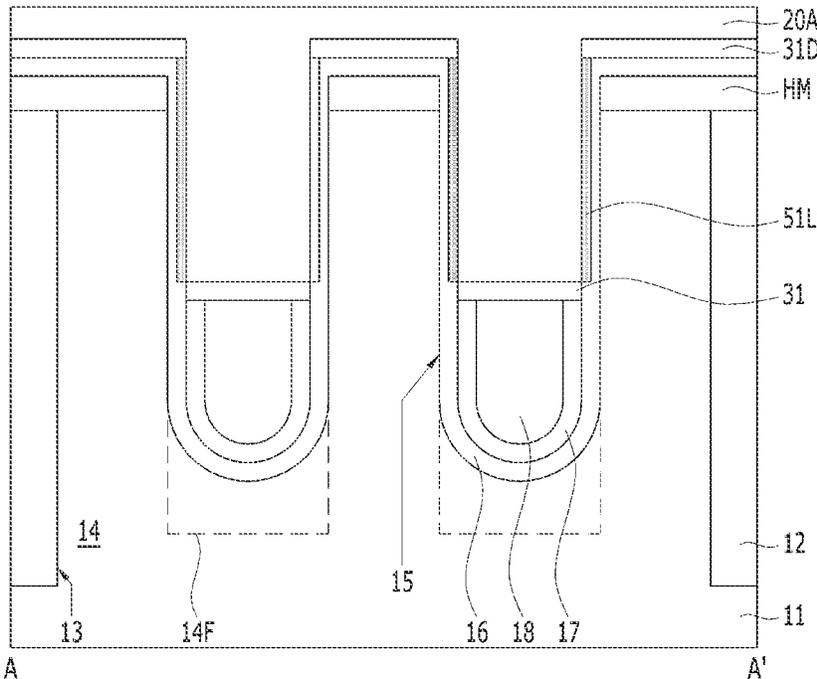


FIG. 16E

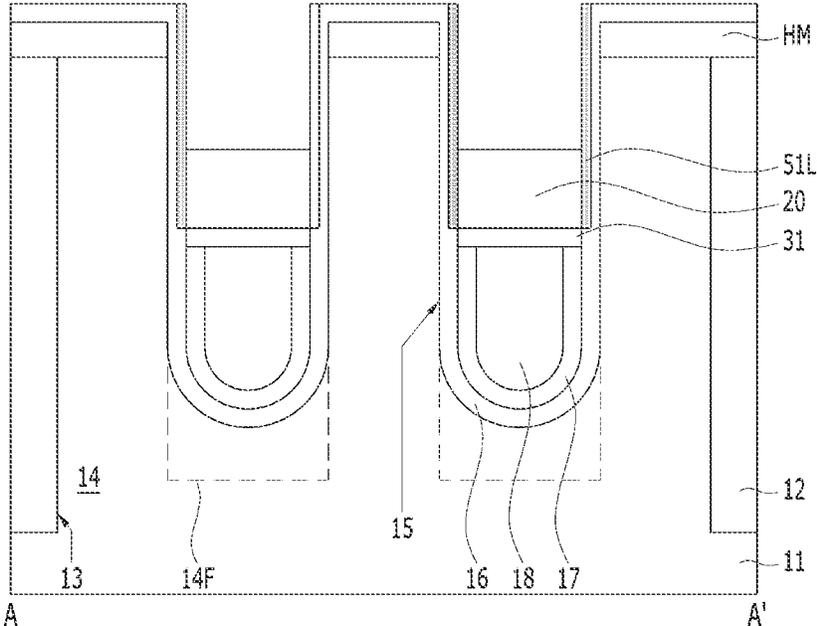


FIG. 16F

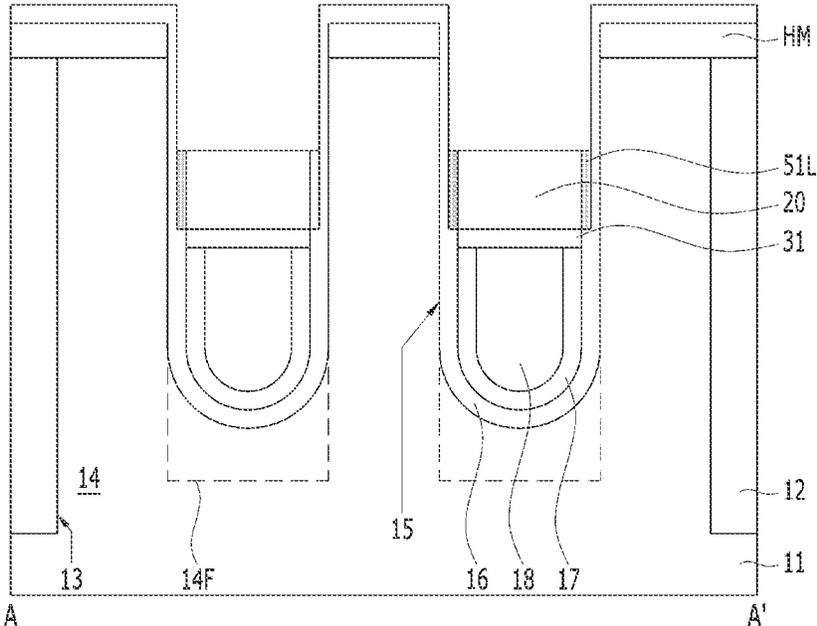


FIG. 16G

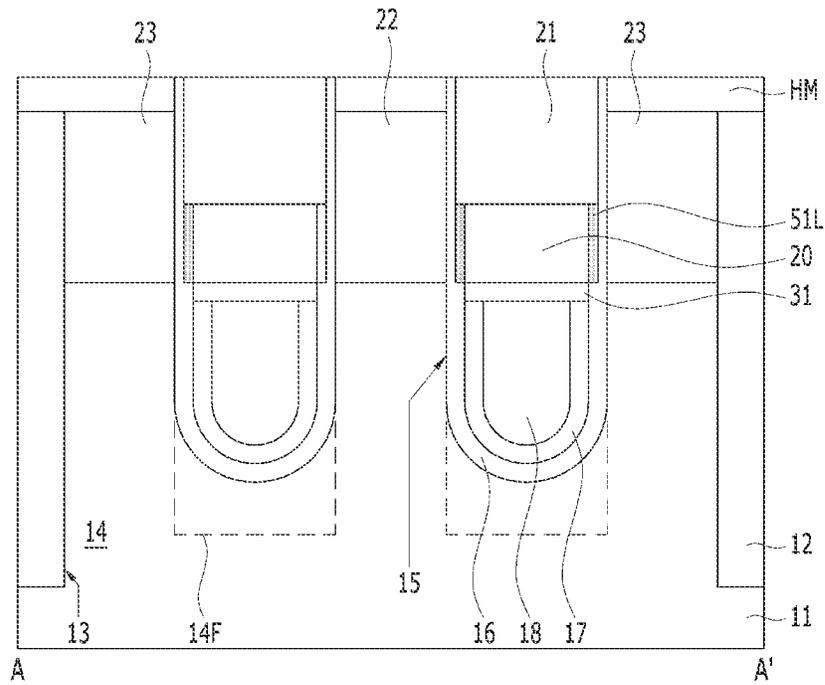


FIG. 17

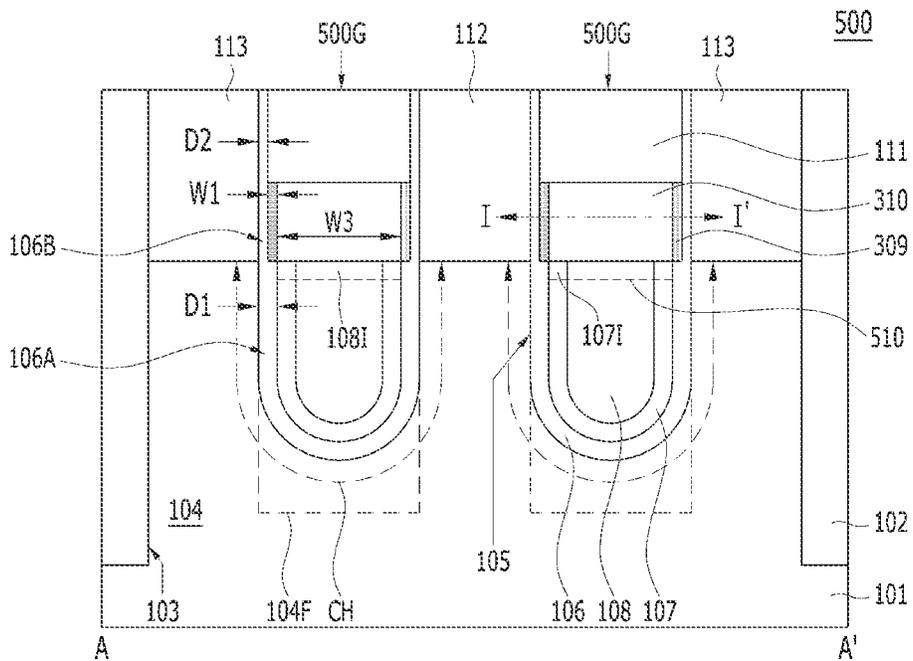


FIG. 18

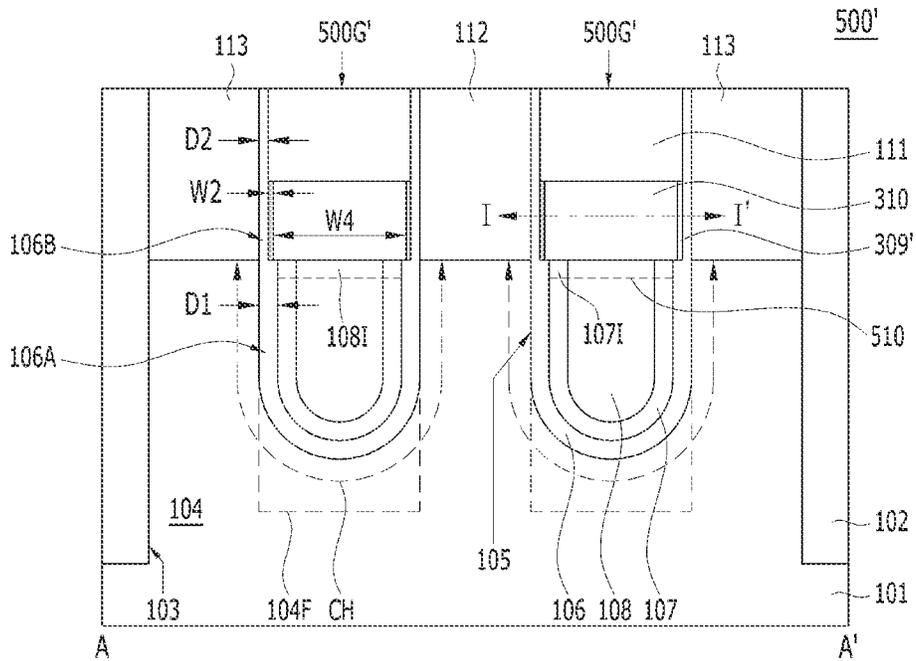


FIG. 19A

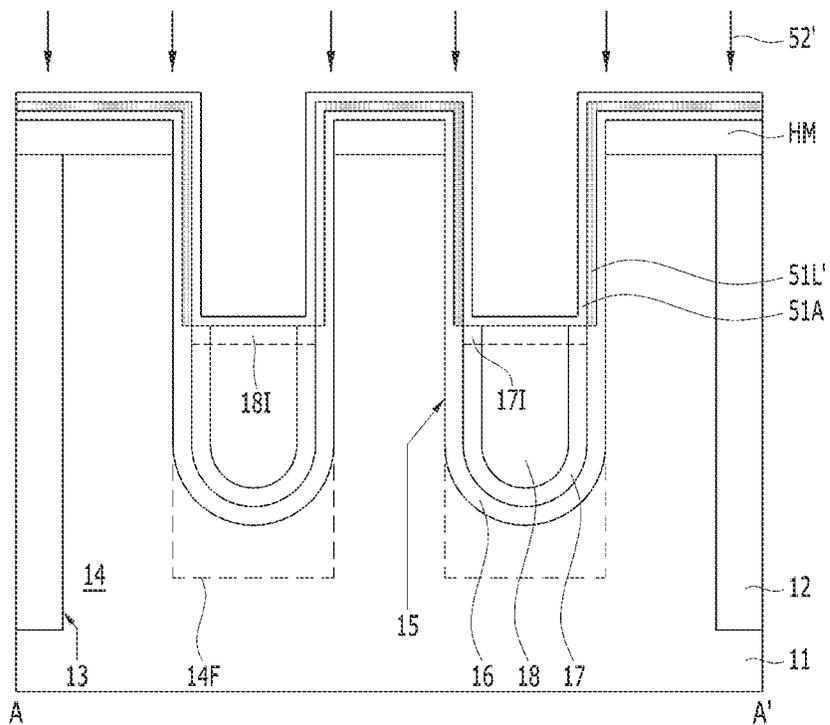


FIG. 19B

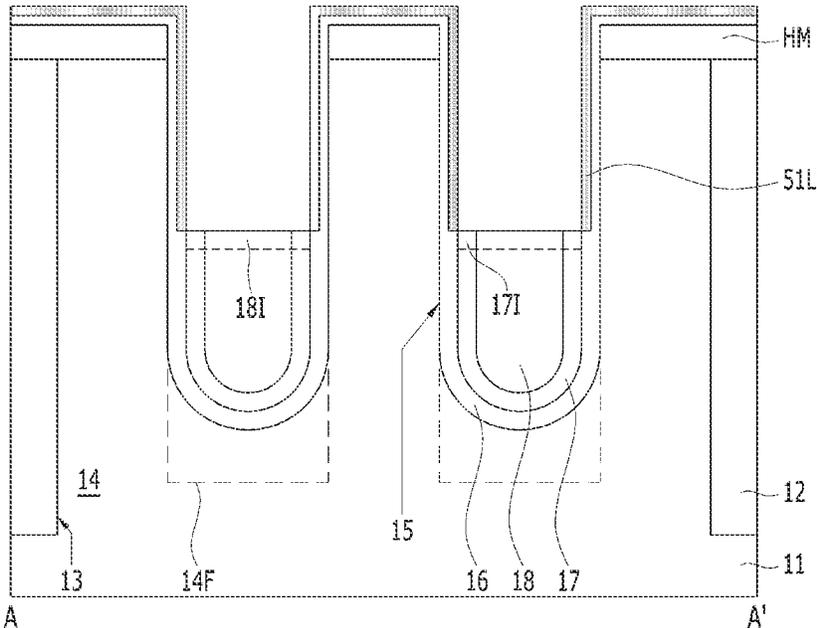


FIG. 19C

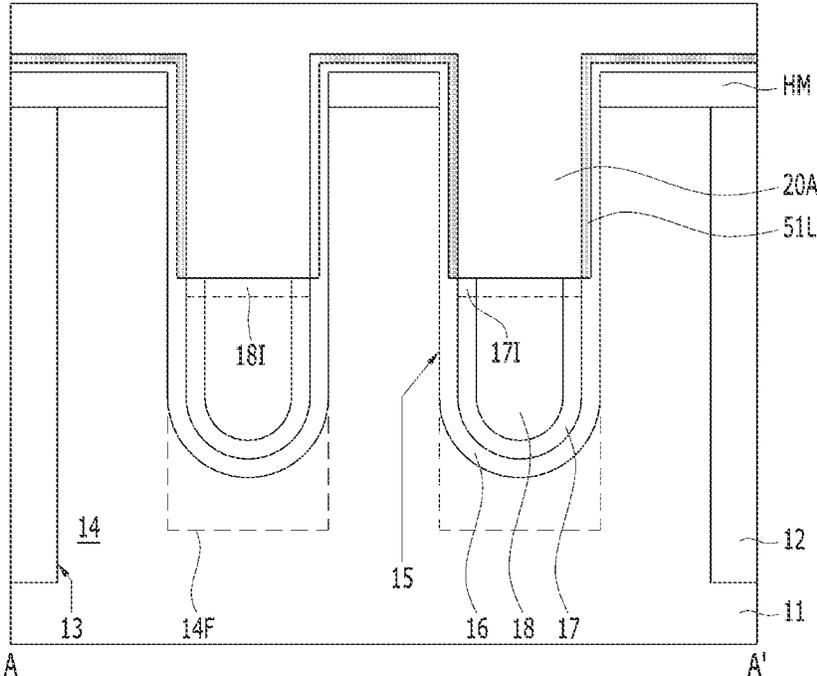


FIG. 19D

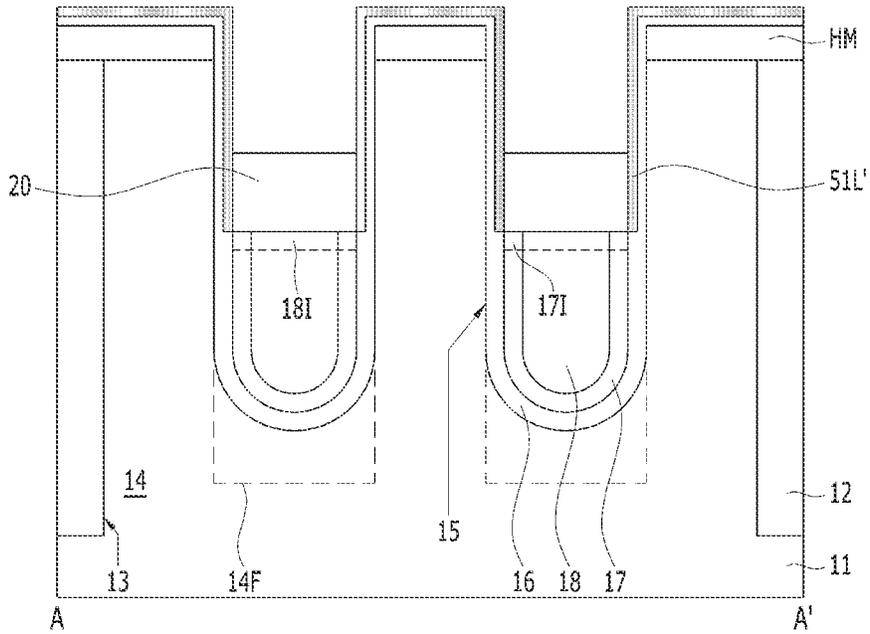


FIG. 19E

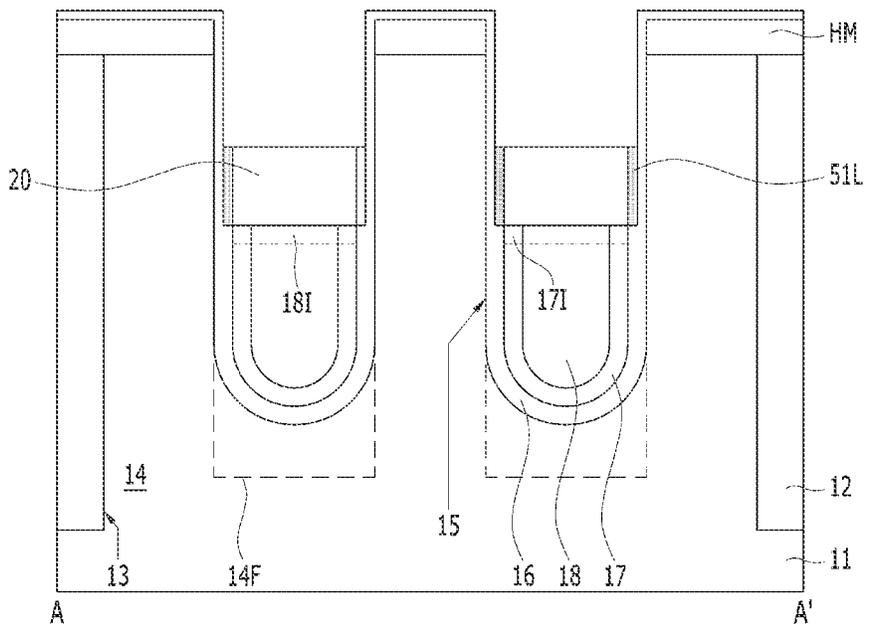


FIG. 19F

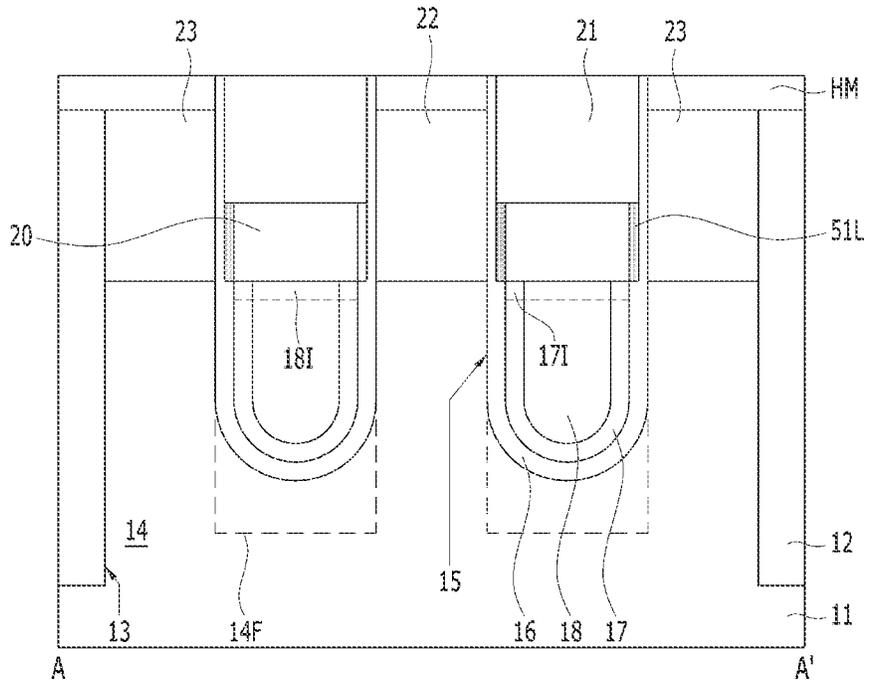


FIG. 20A

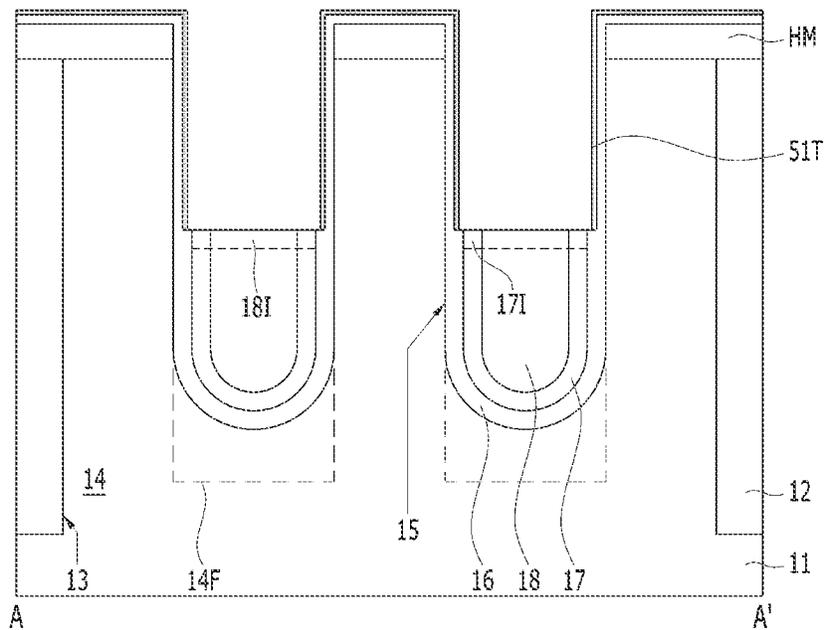


FIG. 20B

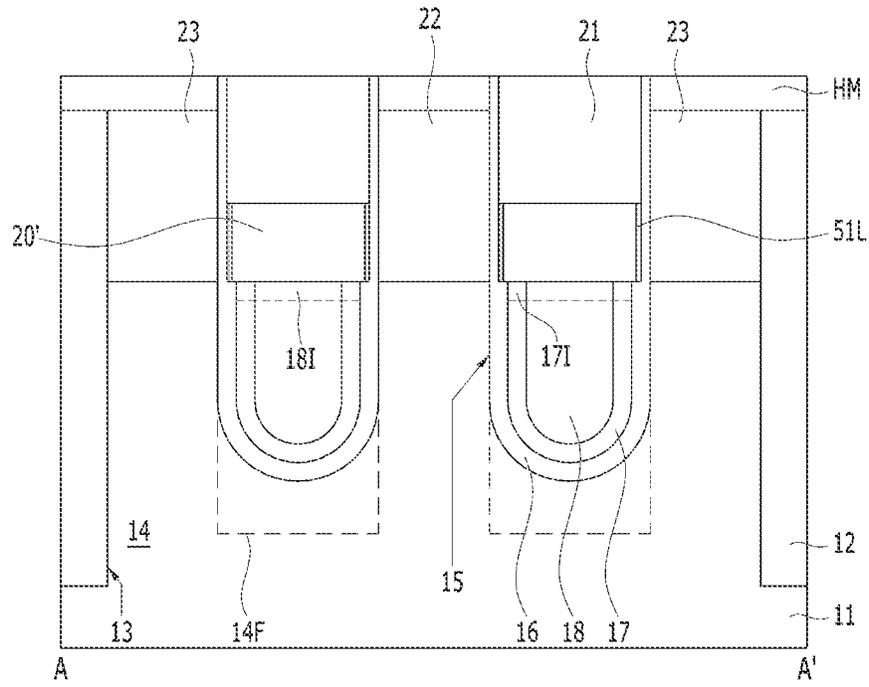


FIG. 21

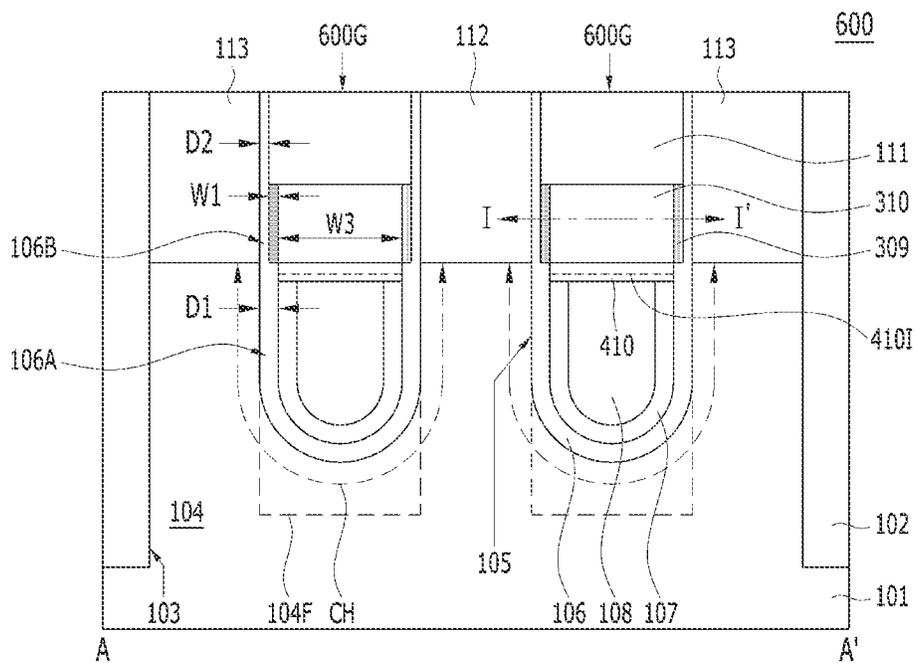


FIG. 24

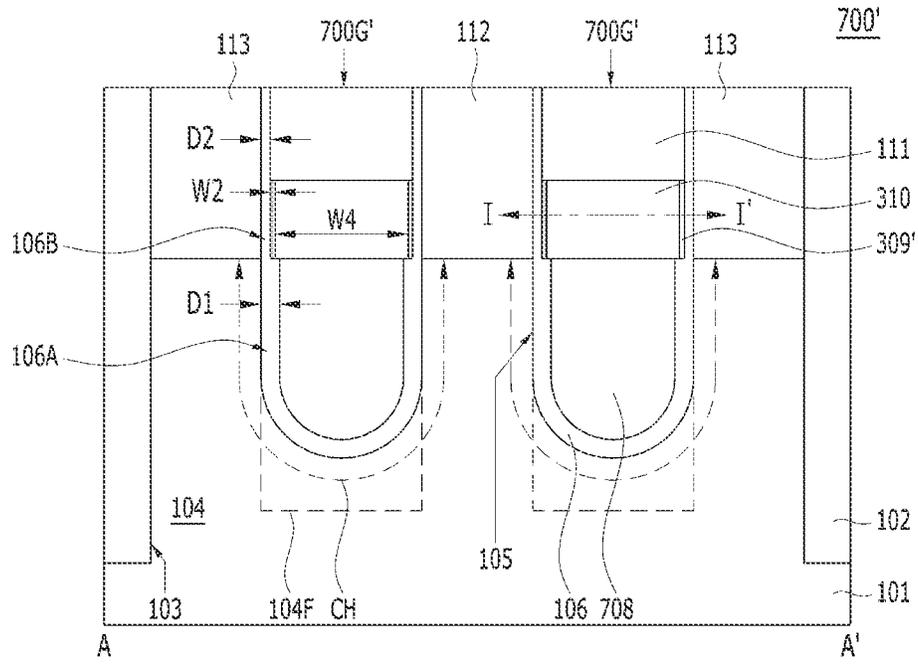


FIG. 25

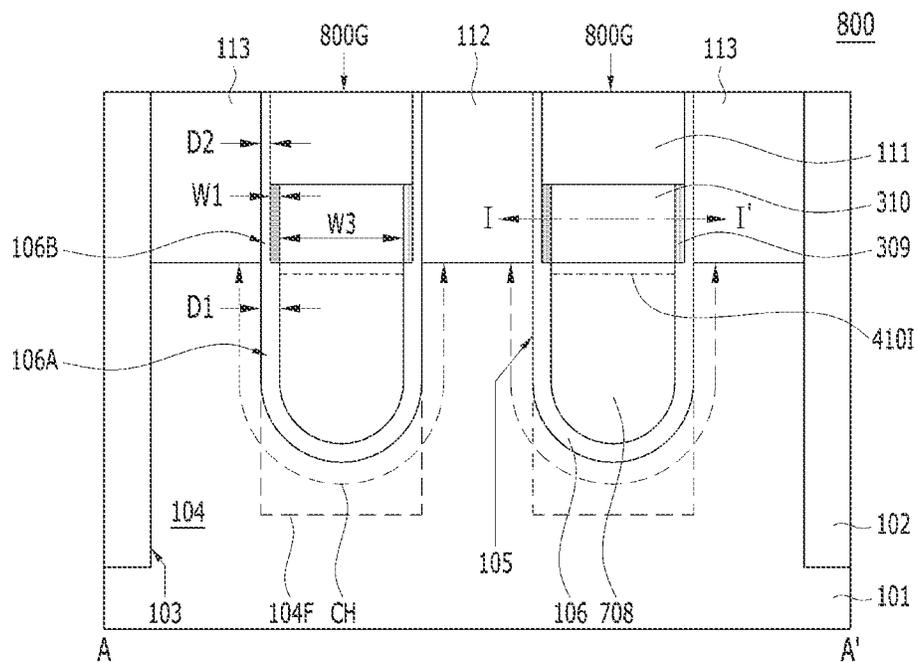


FIG. 26

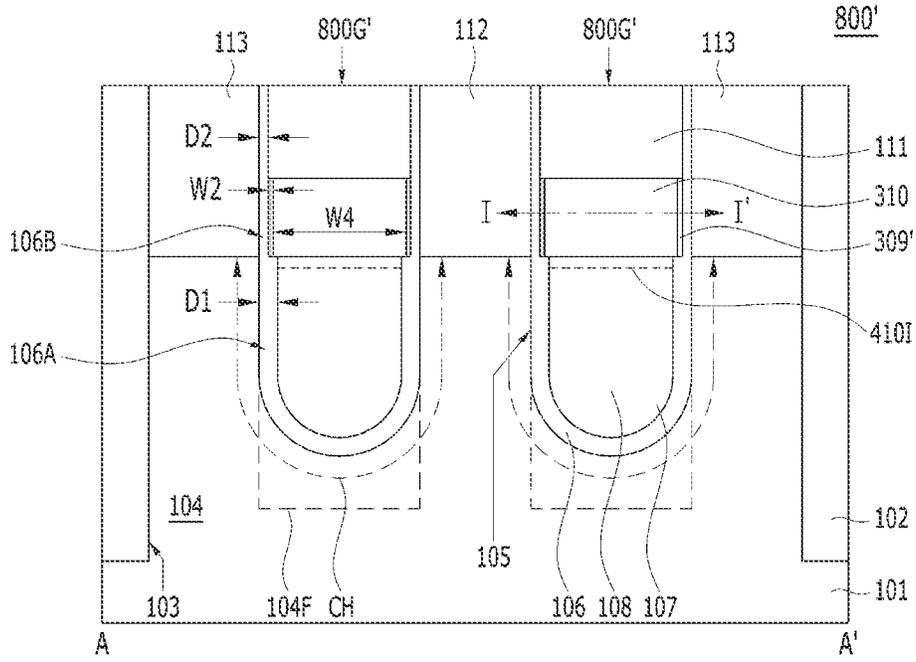


FIG. 27

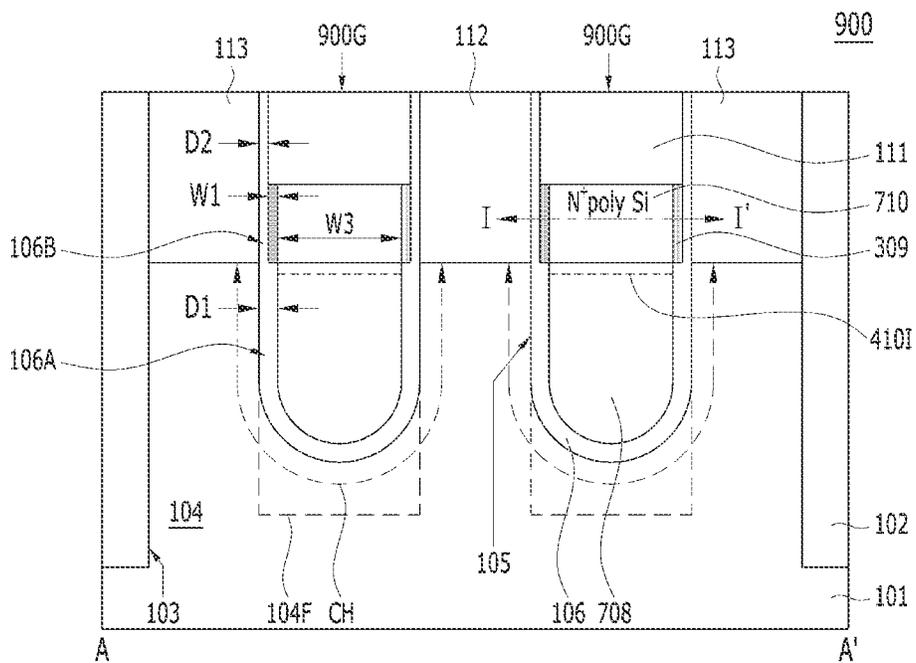


FIG. 28

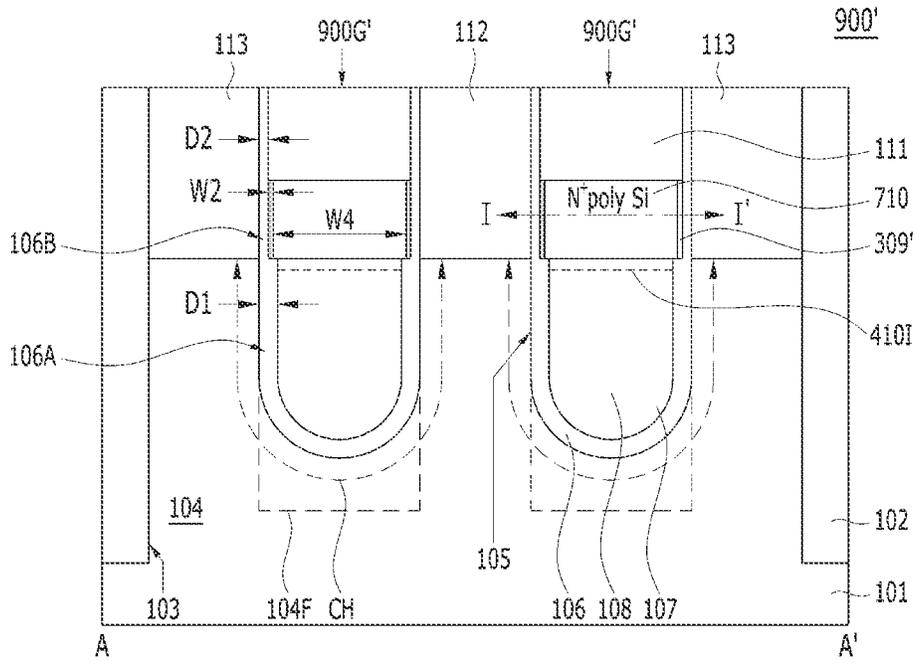


FIG. 29

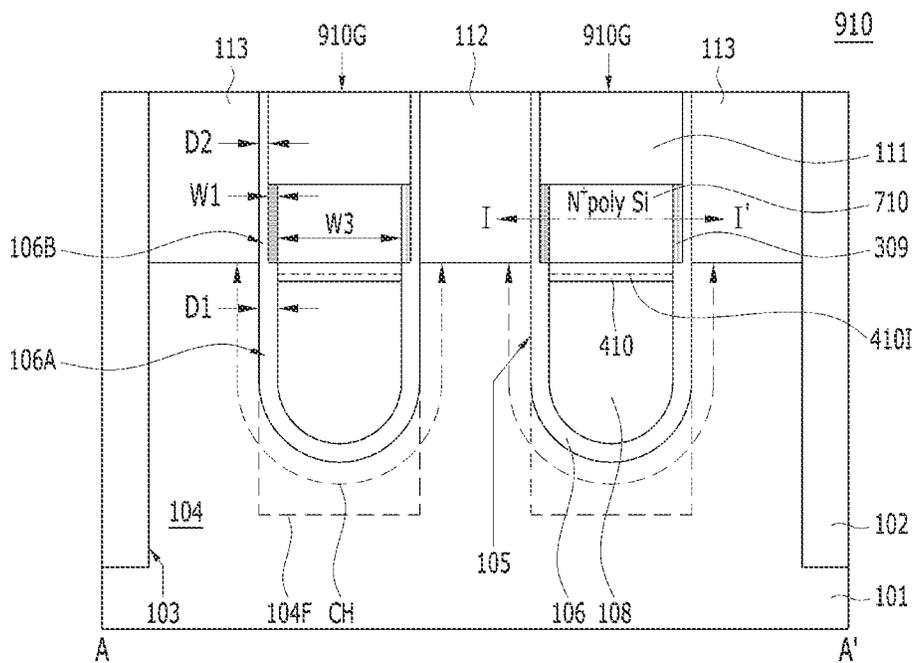


FIG. 30

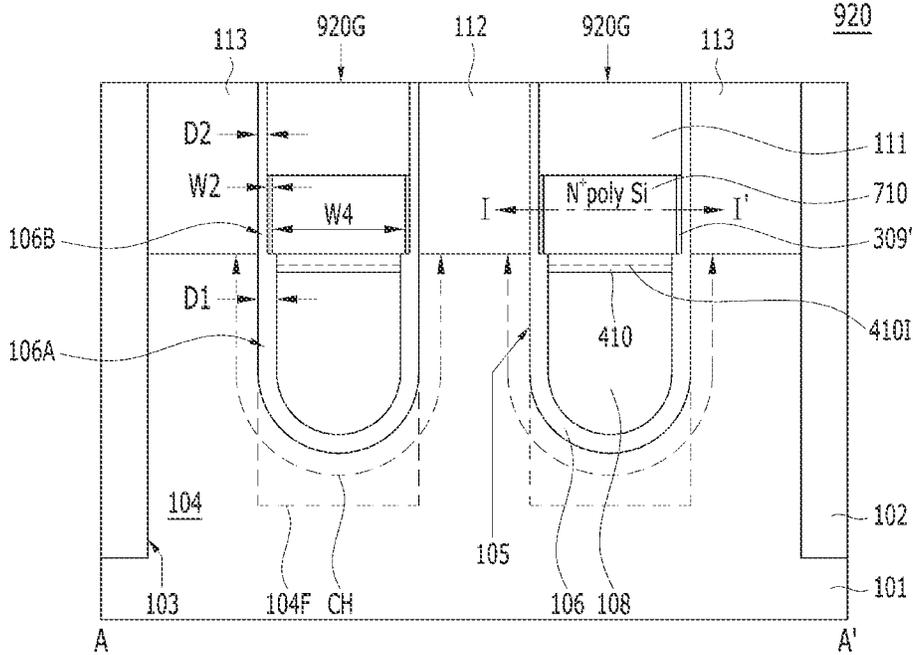


FIG. 31A

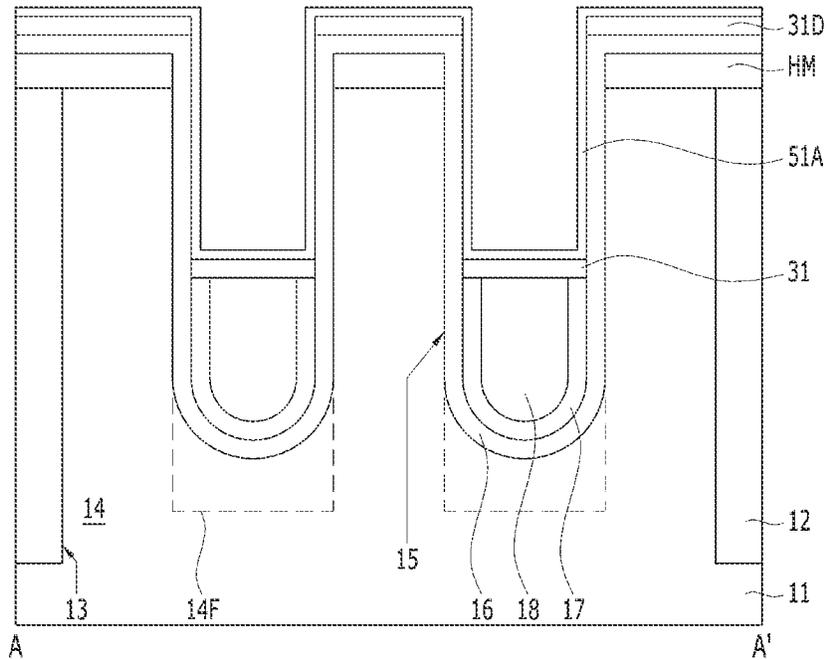


FIG. 31B

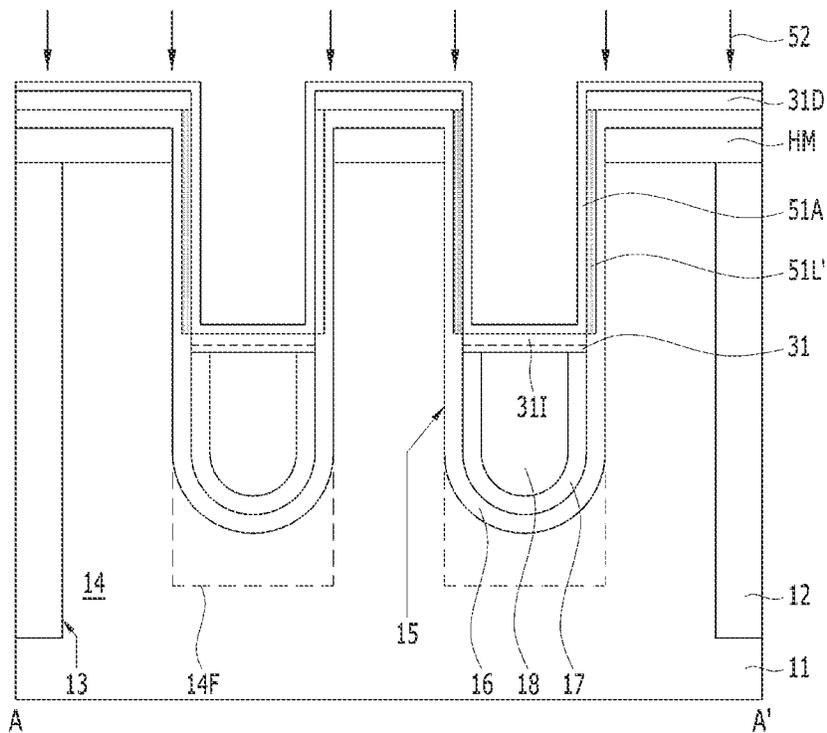


FIG. 31C

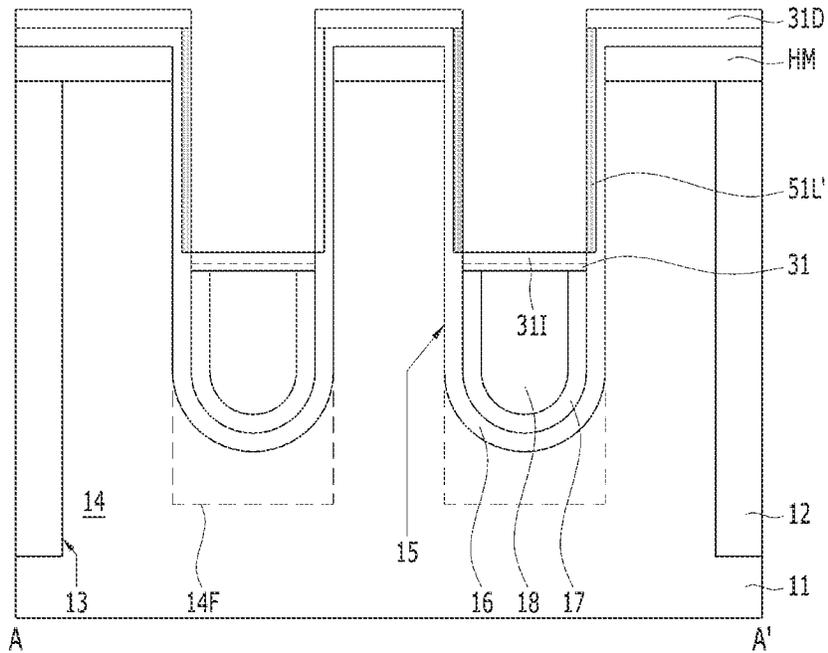


FIG. 31D

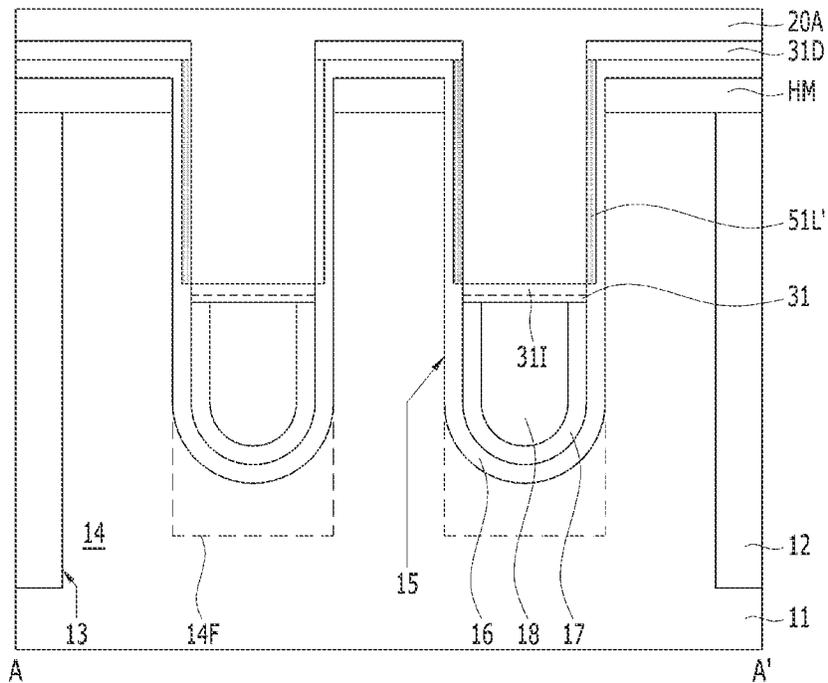


FIG. 31E

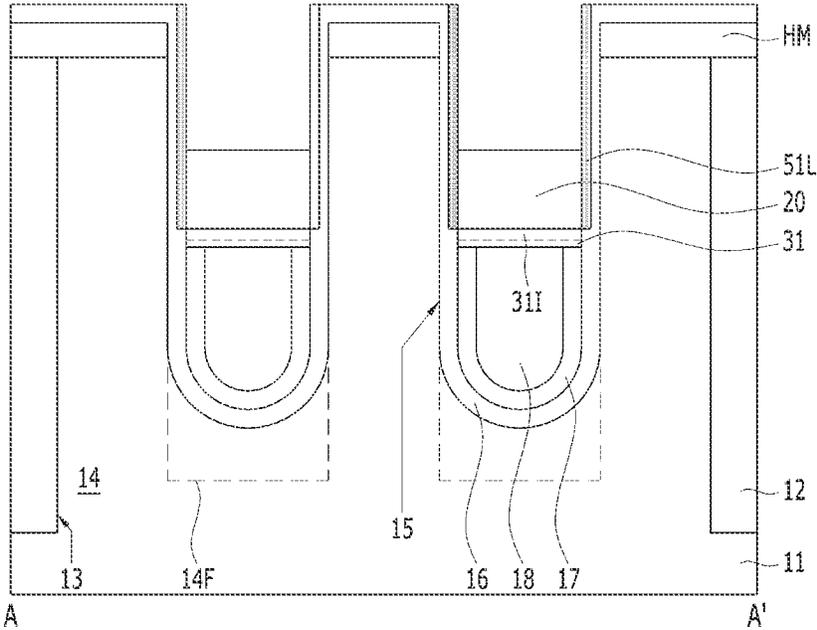


FIG. 31F

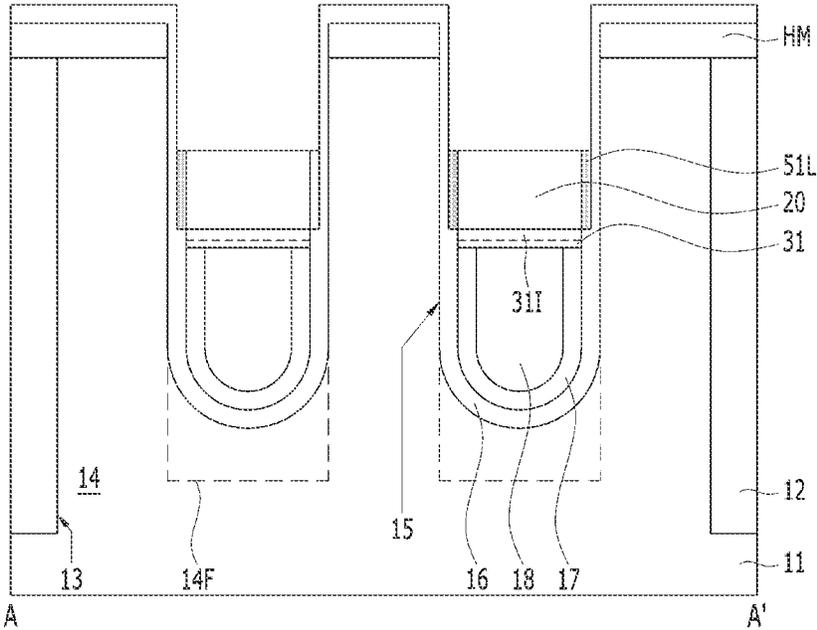


FIG. 31G

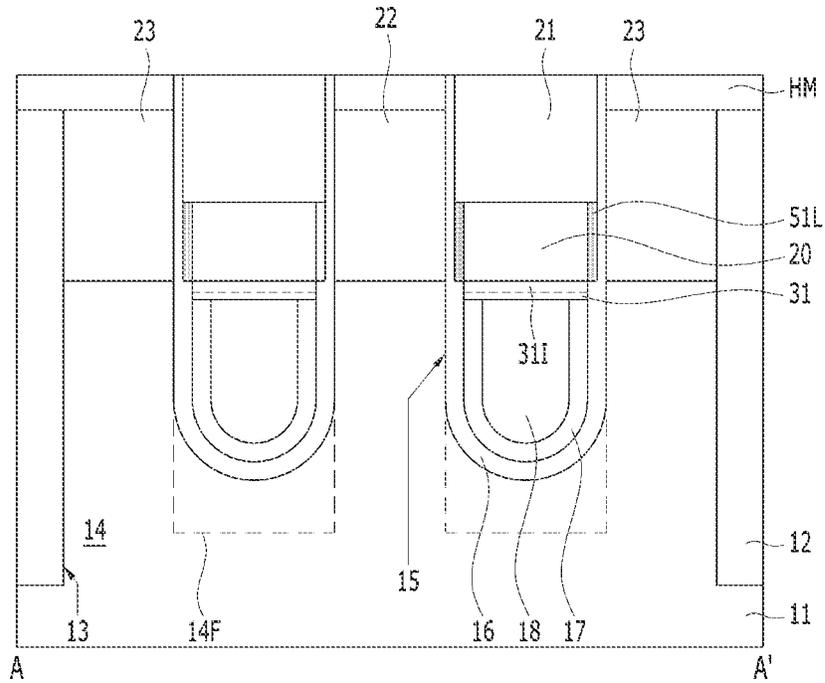
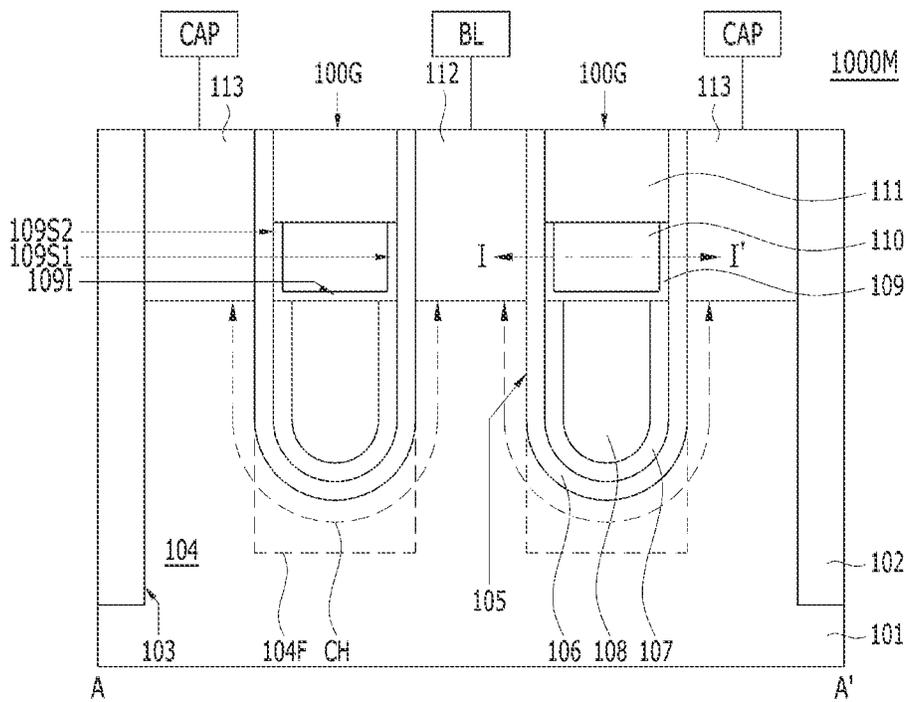


FIG. 32



SEMICONDUCTOR DEVICE HAVING BURIED GATE STRUCTURE AND METHOD FOR FABRICATING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 16/919,368 filed on Jul. 2, 2020, which is a continuation of U.S. patent application Ser. No. 16/119,424 filed on Aug. 31, 2018 and issued as U.S. Pat. No. 10,741,643 on Aug. 11, 2020, which claims benefits of priority of Korean Patent Application No. 10-2018-0021240 filed on Feb. 22, 2018. The disclosure of each of the foregoing application is incorporated herein by reference in its entirety.

BACKGROUND

1. Field

Exemplary embodiments of the present invention relate to a semiconductor device, and more particularly, to a semiconductor device having a buried gate structure, and a method for fabricating the semiconductor device.

2. Description of the Related Art

A metal gate electrode is being used for high performance of a transistor. Particularly, it is required to control a threshold voltage for a high-performance operation in a buried gate-type transistor. However, a gate-induced drain leakage (GIDL) characteristic has a great influence on the performance of the buried gate-type transistor. Reducing GIDL would substantially enhance the performance of the buried gate-type transistor.

SUMMARY

Embodiments of the present invention are directed to an improved semiconductor device capable of reducing gate-induced drain leakage (GIDL), and a method for fabricating the semiconductor device.

In accordance with an embodiment of the present invention, a semiconductor device includes: a substrate; a first source/drain region and a second source/drain region spaced apart from each other by a trench in the substrate; and a gate structure in the trench, wherein the gate structure includes: a gate dielectric layer formed on a bottom and sidewalls of the trench; a first gate electrode positioned in a bottom portion of the trench over the gate dielectric layer; a second gate electrode positioned over the first gate electrode; and a dipole inducing layer formed between the first gate electrode and the second gate electrode and between sidewalls of the second gate electrode and the gate dielectric layer.

In accordance with another embodiment of the present invention, a method for fabricating a semiconductor device includes: forming a trench in a substrate; forming a gate dielectric layer over a bottom and sidewalls of the trench; forming a lower buried portion on the gate dielectric layer, the lower buried portion including a first gate electrode filling a bottom portion of the trench and exposing a portion of the gate dielectric layer; and forming an upper buried portion including a dipole inducing layer that covers a top surface of the first gate electrode and the exposed gate dielectric layer, and a second gate electrode that is positioned over the dipole inducing layer.

In accordance with yet another embodiment of the present invention, a semiconductor device includes: a substrate; a first source/drain region and a second source/drain region spaced apart from each other by a trench in the substrate; and a gate structure which includes: a gate dielectric layer covering a bottom and sidewalls of the trench, a first gate electrode positioned over the gate dielectric layer; a second gate electrode positioned over the first gate electrode, wherein the gate dielectric layer includes: a first portion contacting the first gate electrode; and a second portion including a dipole inducing portion containing a dipole inducing chemical species that contacts the second gate electrode.

In accordance with still another embodiment of the present invention, a method for fabricating a semiconductor device includes: forming a trench in a substrate; forming a gate dielectric layer on a surface of the trench; forming a first gate electrode over the gate dielectric layer to fill a bottom portion of the trench; forming a sacrificial layer including a dipole inducing chemical species over the first gate electrode; exposing the sacrificial layer to a thermal treatment to diffuse the dipole inducing chemical species into a portion of a gate dielectric layer that contacts the sacrificial layer; removing the sacrificial layer; and forming a second gate electrode over the first gate electrode in contact with the dipole inducing chemical species.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plan view illustrating a semiconductor device in accordance with a first embodiment of the present invention.

FIG. 2A is a cross-sectional view of the semiconductor device taken along a line A-A' shown in FIG. 1.

FIG. 2B is a cross-sectional view of the semiconductor device taken along a line B-B' shown in FIG. 1.

FIG. 3 is a cross-sectional view of a semiconductor device in accordance with an example of the embodiment of the present invention.

FIGS. 4A to 4H illustrate an example of a method for fabricating the semiconductor device 100 shown in FIGS. 2A and 2B.

FIGS. 5A to 5C illustrate an example of a method for fabricating the semiconductor device 100' shown in FIG. 3.

FIG. 6 is a cross-sectional view illustrating a semiconductor device 120 in accordance with a second embodiment of the present invention.

FIGS. 7A to 7E illustrate an example of a method for fabricating the semiconductor device 120 shown in FIG. 6.

FIG. 8A is a cross-sectional view illustrating a semiconductor device 200 in accordance with a third embodiment of the present invention.

FIG. 8B is a cross-sectional view illustrating a semiconductor device in accordance with a fourth embodiment of the present invention.

FIGS. 9A to 9E illustrate an example of a method for fabricating the semiconductor device 200 shown in FIG. 8A.

FIG. 10A is a cross-sectional view illustrating a semiconductor device in accordance with a fifth embodiment of the present invention.

FIG. 10B is a magnified view of a dipole inducing portion shown in FIG. 10A.

FIG. 11A is a cross-sectional view illustrating a semiconductor device in accordance with a sixth embodiment of the present invention.

FIG. 11B is a magnified view of a dipole inducing portion.

FIGS. 12A to 12G illustrate an example of a method for fabricating the semiconductor device 300.

FIGS. 13A to 13E illustrate an example of a method for fabricating the semiconductor device 300'.

FIG. 14 is a cross-sectional view illustrating a semiconductor device in accordance with a seventh embodiment of the present invention.

FIG. 15 is a cross-sectional view illustrating a semiconductor device in accordance with an eighth embodiment of the present invention.

FIGS. 16A to 16G illustrate an example of a method for fabricating the semiconductor device 400.

FIG. 17 is a cross-sectional view illustrating a semiconductor device in accordance with a ninth embodiment of the present invention.

FIG. 18 is a cross-sectional view illustrating a semiconductor device in accordance with a 10th embodiment of the present invention.

FIGS. 19A to 19F illustrate an example of a method for fabricating the semiconductor device shown in FIG. 17.

FIGS. 20A and 20B illustrate an example of a method for fabricating the semiconductor device shown in FIG. 18.

FIG. 21 is a cross-sectional view illustrating a semiconductor device in accordance with an 11th embodiment of the present invention.

FIG. 22 is a cross-sectional view illustrating a semiconductor device in accordance with a 12th embodiment of the present invention.

FIG. 23 is a cross-sectional view illustrating a semiconductor device in accordance with a 13th embodiment of the present invention.

FIG. 24 is a cross-sectional view illustrating a semiconductor device in accordance with a 14th embodiment of the present invention.

FIG. 25 is a cross-sectional view illustrating a semiconductor device in accordance with a 15th embodiment of the present invention.

FIG. 26 is a cross-sectional view illustrating a semiconductor device in accordance with a 16th embodiment of the present invention.

FIG. 27 is a cross-sectional view illustrating a semiconductor device in accordance with a 17th embodiment of the present invention.

FIG. 28 is a cross-sectional view illustrating a semiconductor device in accordance with an 18th embodiment of the present invention.

FIG. 29 is a cross-sectional view illustrating a semiconductor device in accordance with a 19th embodiment of the present invention.

FIG. 30 is a cross-sectional view illustrating a semiconductor device in accordance with a 20th embodiment of the present invention.

FIGS. 31A to 31G illustrate an example of a method for fabricating the semiconductor device 600.

FIG. 32 is a cross-sectional view illustrating a memory cell.

DETAILED DESCRIPTION

Exemplary embodiments of the present invention will be described below in more detail with reference to the accompanying drawings. The present invention may, however, be embodied in different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the present invention to those skilled in the art. Throughout

the disclosure, like reference numerals refer to like parts throughout the various figures and embodiments of the present invention.

The drawings are not necessarily to scale and in some instances, proportions may have been exaggerated in order to clearly illustrate features of the embodiments. When a first layer is referred to as being “on” a second layer or “on” a substrate, it not only refers to a case where the first layer is formed directly on the second layer or the substrate but also a case where a third layer exists between the first layer and the second layer or the substrate.

It will be further understood that when an element is referred to as being “connected to”, or “coupled to” another element, it may be directly on, connected to, or coupled to the other element, or one or more intervening elements may be present. In addition, it will also be understood that when an element is referred to as being “between” two elements, it may be the only element between the two elements, or one or more intervening elements may also be present.

The term “or” as used herein means either one of two or more alternatives but not both nor any combinations thereof.

As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

As used herein, singular forms are intended to include the plural forms as well, unless the context clearly indicates otherwise.

It will be further understood that the terms “includes,” and “including” are used interchangeably in this specification with the open-ended terms “comprises,” and “comprising,” to specify the presence of any stated elements and to not preclude the presence or addition of one or more other non-stated elements.

Unless otherwise defined, all terms including technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the present invention belongs in view of the present disclosure. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the present disclosure and the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

Hereinafter, in the following embodiments of the present invention, a threshold voltage V_t depends on a flat-band voltage V_{FB} . The flat-band voltage V_{FB} depends on a work function. The work function may be engineered by diverse methods. For example, the work function may be controlled by selecting a gate electrode material and a material for the region disposed between the gate electrode and a channel. The flat-band voltage may be shifted by increasing or decreasing the work function. A high work function may shift the flat-band voltage in a positive direction, and a low work function may shift the flat-band voltage in a negative direction. In the following embodiments, the threshold voltage may be adjusted or modified by shifting the flat-band voltage, regardless of whether a channel dopant concentration is decreased or channel doping is omitted altogether. For example, the flat-band voltage may be lowered by a low work function material or a dipole, thereby enhancing the suppression of a gate-induced drain leakage (GIDL).

Hereinafter, in accordance with embodiments of the present invention, a buried gate structure may be positioned in a gate trench. The buried gate structure may include a gate electrode. The gate electrode may fill the gate trench. Thus, the gate electrode may be referred to also herein as ‘a buried gate electrode.’ The gate electrode may include a first gate electrode and a second gate electrode. For example, the gate

electrode may be a dual gate electrode. The first gate electrode may fill a lower portion of the gate trench. The second gate electrode may fill an upper portion of the gate trench. The second gate electrode may be positioned over the first gate electrode. The first gate electrode may overlap with a channel. The second gate electrode may overlap with a first source/drain region and a second source/drain region.

FIG. 1 is a plan view illustrating a semiconductor device 100 in accordance with a first embodiment of the present invention. FIG. 2A is a cross-sectional view of the semiconductor device 100 taken along a line A-A' shown in FIG. 1. FIG. 2B is a cross-sectional view of the semiconductor device 100 taken along a line B-B' shown in FIG. 1.

Referring to FIG. 1, the semiconductor device 100 may include a buried gate structure 100G, a first source/drain region 112, and a second source/drain region 113. An isolation layer 102 and an active region 104 may be formed over a substrate 101. The first and the second source/drain regions 112 and 113 may be formed inside the active region 104. A gate trench 105 may cross the active region 104 and the isolation layer 102 and the buried gate structure 100G may be formed inside the gate trench 105. A channel CH may be formed between the first source/drain region 112 and the second source/drain region 113 with the buried gate structure 100G between them. The channel CH may extend conformally along an outside surface of the profile of the gate trench 105. The semiconductor device 100 may be a portion of a memory cell. For example, the semiconductor device 100 may be a cell transistor of a DRAM.

The semiconductor device 100 may be formed over the substrate 101. The substrate 101 may be made of a material suitable for semiconductor processing. The substrate 101 may be any suitable semiconductor substrate. In an embodiment, the substrate 101 may be formed of a material containing silicon. The substrate 101 may include silicon, monocrystalline silicon, polysilicon, amorphous silicon, silicon germanium, monocrystalline silicon germanium, polycrystalline silicon germanium, carbon doped silicon, combinations thereof or a multilayer thereof. The substrate 101 may include other semiconductor materials such as germanium. The substrate 101 may include a III/V-group semiconductor substrate, for example, a compound semiconductor substrate, such as GaAs. The substrate 101 may include a Silicon-On-Insulator (SOI) substrate.

The isolation layer 102 and the active region 104 may be formed on the substrate 101. The active region 104 may be defined by the isolation layer 102. The isolation layer 102 may be a Shallow Trench Isolation (STI) region formed by trench etching. The isolation layer 102 may be formed by filling a shallow trench, e.g., an isolation trench 103, with a dielectric material. For, example, the isolation layer 102 may include a silicon oxide, a silicon nitride, or a combination thereof.

The gate trench 105 may be formed in the substrate 101. Referring to the plan view of FIG. 1, the gate trench 105 may have an elongated shape extending in one direction. The gate trench 105 may be line-shaped extending in one direction. The gate trench 105 may have a form of a line traversing the active region 104 and the isolation layer 102. The gate trench 105 may have a shallower depth than the isolation trench 103. A bottom portion of the gate trench 105 may have a curvature, i.e., a bottom portion of the gate trench 105 may have a curved surface.

A first source/drain region 112 and a second source/drain region 113 may be formed inside the active region 104. The first source/drain region 112 and the second source/drain region 113 may be doped with a conductive dopant. For

example, the conductive dopant may include at least one of phosphorus (P), arsenic (As), antimony (Sb), or boron (B). The first source/drain region 112 and the second source/drain region 113 may be doped with a dopant of the same conductivity type. The first source/drain region 112 and the second source/drain region 113 may be positioned in the active region 104 on either side of the gate trench 105, meaning that the first source/drain region 112 may be adjacent one side of the gate trench 105 while the second source/drain region 113 may be adjacent the other side of the gate trench 105. The bottom surfaces of the first source/drain region 112 and the second source/drain region 113 may be positioned at a predetermined depth from the top surface of the active region 104. The first source/drain region 112 and the second source/drain region 113 may be in contact with the sidewalls of the gate trench 105. The bottom surfaces of the first source/drain region 112 and the second source/drain region 113 may be higher than the bottom surface of the gate trench 105.

The gate trench 105 may include a first trench 105A and a second trench 105B. The first trench 105A may be formed in the active region 104. The second trenches 105B may be formed in the isolation layer 102. The first trench 105A and the second trench 105B may be formed to be consecutively extended from the first trench 105A and the second trench 105B. In the gate trench 105, the first trench 105A and the second trench 105B may have bottom surfaces positioned at different levels. For example, the bottom surface of the first trench 105A may be positioned at a higher level than the bottom surface of the second trench 105B. The height difference between the first trench 105A and the second trench 105B may be caused as the isolation layer 102 is recessed. Thus, the second trench 105B may include a recessed region R having a lower bottom surface than the bottom surface of the first trench 105A. A fin region 104F may be formed in the active region 104 due to a height difference between the first trench 105A and the second trench 105B. Therefore, the active region 104 may include the fin region 104F.

As described above, the fin region 104F may be formed below the first trench 105A, and the sidewall of the fin region 104F may be exposed by the recessed isolation layer 102F. The fin region 104F may be a portion where a channel is formed. The fin region 104F may be referred to also herein as a saddle fin. The fin region 104F may increase the width of the channel and improve the electrical characteristics.

In accordance with an embodiment, the fin region 104F may be omitted.

The buried gate structure 100G may be positioned in the gate trench 105. The buried gate structure 100G may be extended into the isolation layer 102 as the buried gate structure 100G is disposed in the active region 104 between the first source/drain region 112 and the second source/drain region 113. The bottom surface of a portion of the buried gate structure 100G disposed in the active region 104 and the bottom surface of a portion of the buried gate structure 100G disposed in the isolation layer 102 may be positioned at different levels. When the fin region 104F is omitted, the bottom surface of the portion of the buried gate structure 100G disposed in the active region 104 and the bottom surface of the portion of the buried gate structure 100G disposed in the isolation layer 102 may be positioned at the same level.

The buried gate structure 100G may include a gate dielectric layer 106, a barrier 107, a first gate electrode 108, a dipole inducing layer 109, a second gate electrode 110, and a capping layer 111.

The gate dielectric layer **106** may be conformally formed on the bottom and sidewalls of the gate trench **105**. The gate dielectric layer **106** may include a silicon oxide, a silicon nitride, a silicon oxynitride, a high-k material, or a combination thereof. The high-k material may include a material having a greater dielectric constant than the dielectric constant of a silicon oxide. For example, the high-k material may include a material having a greater dielectric constant than 3.9. In accordance with an embodiment, the high-k material may include a material having a greater dielectric constant than 10. In accordance with an embodiment, the high-k material may include a material having a dielectric constant of 10 to 30. The high-k material may include at least one metallic element. The high-k material may include hafnium-containing material. The hafnium containing material may include a hafnium oxide, a hafnium silicon oxide, a hafnium silicon oxynitride, or a combination thereof. In accordance with an embodiment, the high-k material may be selected from a group including a lanthanum oxide, a lanthanum aluminum oxide, a zirconium oxide, a zirconium silicon oxide, a zirconium silicon oxynitride, an aluminum oxide, and combinations thereof. As for the high-dielectric material, other high-k materials known in the art may be optionally used. The gate dielectric layer **106** may include a metal oxide.

The barrier **107** may be formed over the gate dielectric layer **106**. A first gate electrode **108** may be formed over the barrier **107**. The top surfaces of the barrier **107** and the first gate electrode **108** may be at a lower level than the top surface of the substrate **101**. The barrier **107** and the first gate electrode **108** may be formed to fill the bottom portion of the gate trench **105**. The barrier **107** and the first gate electrode **108** may be of low resistance materials to lower a gate sheet resistance. The barrier **107** and the first gate electrode **108** may be made of metal-based materials.

The barrier **107** may include a metal nitride. The barrier **107** may be formed of a tantalum nitride (Ta₂N₃) or a titanium nitride (TiN). In accordance with an embodiment, the barrier **107** may have a high work function. Herein, the high work function may refer to a work function that is higher than a mid-gap work function of silicon. A low work function may refer to a work function that is lower than the mid-gap work function of silicon. The high work function may be higher than approximately 4.5 eV, and the low work function may be lower than approximately 4.5 eV.

The barrier **107** may have an increased high work function. The barrier **107** may include a metal silicon nitride. The metal silicon nitride may be a metal nitride doped with silicon. The barrier **107** may be a metal silicon nitride with a controlled silicon content. For example, the barrier **107** may be a tantalum silicon nitride (TaSiN) or a titanium silicon nitride (TiSiN). A titanium nitride may have a high work function, and the titanium nitride may contain silicon to further increase the work function of the titanium nitride. The titanium silicon nitride may have an adjusted silicon content to have an increased high work function. In order to have the increased high work function, the content (atomic percent: at %) of silicon in the titanium silicon nitride may be approximately 20 at % or less. In a comparative example, for a low work function, the content of silicon in the titanium silicon nitride may be approximately 30 at % or more.

The first gate electrode **108** and the second gate electrode **110** may include a metal or a metal nitride. The first gate electrode **108** and the second gate electrode **110** may include tungsten or a titanium nitride. When tungsten is used as the first gate electrode **108**, the gate dielectric layer **106** may be damaged when making the first gate electrode **108**. For

example, the tungsten layer may be deposited using a tungsten hexafluoride (WF₆) gas, and the gate dielectric layer **106** may be attacked by the fluorine used in the making of the tungsten layer. To address this concern the barrier **107** may be formed between the first gate electrode **108** and the gate dielectric layer **106** to prevent the fluorine from contacting the gate dielectric layer **106**. In an embodiment, the first gate electrode **108** may be formed of tungsten (W), and the second gate electrode **110** may be formed of a titanium nitride (TiN). The barrier between the second gate electrode **110** and the gate dielectric layer **106** may be omitted.

The stack of the barrier **107** and the first gate electrode **108** may be referred to also herein as ‘a lower conductive layer’, and the second gate electrode **110** may be referred to also herein as ‘an upper conductive layer’. The lower conductive layer may include a metal or a metal nitride. Also, the lower conductive layer may include a metal nitride/metal stack in which a metal is formed over a metal nitride. The upper conductive layer may be formed only of a metal nitride.

The capping layer **111** may be formed over the second gate electrode **110** to protect the second gate electrode **110**. The capping layer **111** may be made of a suitable dielectric material including, for example, a silicon nitride, a silicon oxynitride, or a combination thereof. In an embodiment, the capping layer **111** may include a combination of a silicon nitride and a silicon oxide. The capping layer **111** may include a silicon nitride liner and a spin-on-dielectric (SOD) material.

The dipole inducing layer **109** may include an interface portion **1091** and side portions **109S1** and **109S2**. The interface portion **1091** may be formed between the first gate electrode **108** and the second gate electrode **110**. The side portions **109S1** and **109S2** may be formed between the second gate electrode **110** and the gate dielectric layer **106**. The side portions **109S1** and **109S2** may include a first side portion **109S1** and a second side portion **109S2**. The first side portion **109S1** may be positioned between the first source/drain region **112** and the second gate electrode **110**. The second side portion **109S2** may be positioned between the second source/drain region **113** and the second gate electrode **110**.

As described above, the dipole inducing layer **109** may include the interface portion **1091** and the first and second side portions **109S1** and **109S2** that are extended continuously from both ends of the interface portion **1091**. The interface portion **1091** may directly contact the first gate electrode **108** and the second gate electrode **110**. The first and second side portions **109S1** and **109S2** may directly contact the gate dielectric layer **106** and the second gate electrode **110**. The first and second side portions **109S1** and **109S2** may be in direct contact with the sidewalls of the second gate electrode **110**. Both ends of the interface portion **1091** may directly contact the top surface of the barrier **107**. The top surface of the first and second side portions **109S1** and **109S2** and the top surface of the second gate electrode **110** may be at the same level. The top surfaces of the first and second side portions **109S1** and **109S2** may be at a lower level than the top surface of the active region **104**.

The dipole inducing layer **109** may overlap with the first source/drain region **112** and the second source/drain region **113**. The dipole inducing layer **109** may overlap with the first and second source/drain regions **112** and **113** in the horizontal direction, e.g., along line I-I' of FIG. 2A, with the gate dielectric layer **106** disposed therebetween. The dipole inducing layer **109** may partially overlap with the first and second source/drain regions **112** and **113**. The first and

second side portions **109S1** and **109S2** may partially overlap with the first and second source/drain regions **112** and **113**. That is, the top surfaces of the first and second side portions **109S1** and **109S2** may be at a lower level than the top surfaces of the first and second source/drain regions **112** and **113**. The second gate electrode **110** may overlap with the first and second source/drain regions **112** and **113** in the horizontal direction (see the reference symbol I-I') with the dipole inducing layer **109** and the gate dielectric layer **106** disposed therebetween. The lowest portion of the dipole inducing layer **109**, that is, the interface portion **1091**, may be at the same level as the lowest portions of the first portion of the first source/drain region **112** and the second source/drain region **113**. The dipole inducing layer **109** may not overlap with the channel CH in the horizontal direction, thus, the dipole inducing layer **109** may not affect the dose of the channel CH.

The dipole inducing layer **109** may be made of any suitable dielectric material. The dipole inducing layer **109** may include a high-k material. The dipole inducing layer **109** and the gate dielectric layer **106** may be made of different materials. The dipole inductive layer **109** may have a higher dielectric constant than that of the gate dielectric layer **106**.

The interface portion **1091** of the dipole inducing layer **109** may be sufficiently thin for allowing electrical connection between the first gate electrode **108** and the second gate electrode **110**. In accordance with an embodiment, the dipole inducing layer **109** may include a monolayer. The dipole inducing layer **109** may have a thickness of approximately 10 Å or less. For example, a lanthanum oxide (La_2O_3) having a thickness of approximately 10 Å or less may be employed according to an embodiment and may electrically connect the first gate electrode **108** and the second gate electrode **110** to each other. The dipole inducing layer **109** may be referred to also herein as 'ultra-thin dipole inducing layer'.

The dipole inducing layer **109** may include a material having a lower oxygen atom areal density than that of the gate dielectric layer **106**. The dipole inducing layer **109** and the gate dielectric layer **106** may generate a dipole in a direction of decreasing the work function due to the difference of the oxygen atom areal density. The dipole may reduce the effective work function value of the second gate electrode **110**. Thus, the dipole inducing layer **109** may also be referred to herein as 'a low work function liner'.

The dipole generation mechanism will be described as follows. The oxygen atom areal density in the dipole inducing layer **109** may be lower than the oxygen atom areal density of the gate dielectric layer **106**. Due to the difference in the oxygen atom areal density, the oxygen atoms of the gate dielectric layer **106** may be diffused into the dipole inducing layer **109**. As the oxygen atoms diffuse, the gate dielectric layer **106** may become positively charged, and the dipole inducing layer **109** may become negatively charged. Thus, a dipole may be induced on the interface between the positively charged gate dielectric layer **106** and the negatively charged dipole inducing layer **109**. When the dipole is induced, the energy band of the second gate electrode **110** may be increased, so that the second gate electrode **110** may have a decreased work function. As a result, the gate-induced drain leakage (GIDL) may be suppressed substantially as the work function of the second gate electrode **110** decreases. The dipole inducing layer **109** may not overlap with the channel CH in the horizontal direction. When the dipole inducing layer **109** and the channel CH overlap with each other, it is difficult to adjust the threshold voltage due

to the induction of a low work function. The dipole inducing layer **109** may be in direct contact with the gate dielectric layer **106** and the second gate electrode **110** for decreasing the work function of the second gate electrode **110**.

The gate dielectric layer **106** may include a silicon oxide (SiO_2), and the dipole inducing layer **109** may be made of a material having a lower oxygen atom areal density than the silicon oxide. The dipole inducing layer **109** may include a metal atom. The dipole inducing layer **109** may include a metal oxide. The dipole inducing layer **109** may include a metal oxide monolayer. The dipole inducing layer **109** may include a lanthanum atom. The dipole inducing layer **109** may include a lanthanum oxide or a lanthanum oxide monolayer. The lanthanum atom may be referred to also herein as 'a dipole inducing chemical species (DICS).' For example, the oxygen atom areal density ratio of the lanthanum oxide to the silicon oxide (SiO_2) may be approximately 0.77.

In accordance with an embodiment, the dipole inducing layer **109** may include an yttrium oxide (Y_2O_3), a germanium oxide (GeO_2), a lutetium oxide (Lu_2O_3), or a strontium oxide (SrO).

In accordance with an embodiment, the gate dielectric layer **106** may include a first metal oxide, and the dipole inducing layer **109** may include a second metal oxide having a lower oxygen atom areal density than that of the first metal oxide.

According to the above description, the dipole inducing layer **109** may form a dipole, and the dipole may lower the flat-band voltage. As a result, the suppression of the gate-induced drain leakage (GIDL) may be improved. Since the dipole inducing layer **109** is thin, a conductive path through which the first gate electrode **109** and the second gate electrode **110** are electrically connected may be formed.

In addition, since the second gate electrode **110** has a barrier-less structure, the gate sheet resistance may be lowered. Also, since the upper portion of the gate trench **105** is filled with the second gate electrode **110** and the dipole inducing layer **109** without a barrier, the filling characteristics of the second gate electrode **110** may be improved.

In a comparative example, when a barrier such as TiN is added between the second gate electrode **110** and the dipole inducing layer **109**, not only the gate sheet resistance is increased but also defects, such as voids, may be formed in the second gate electrode **110**.

As another comparative example, a barrier such as TiN may be added between the dipole inducing layer **109** and the gate dielectric layer **106**. For example, DICS, e.g., La, may be diffused from the dipole inducing layer **109** into the TiN barrier. As a result, a lanthanum atom-diffused TiN barrier (La-diffused TiN barrier) may be in direct contact with the gate dielectric layer **106**. However, when the lanthanum atom-diffused TiN barrier and the gate dielectric layer **106** are in direct contact with each other, the effect of suppressing the gate-induced drain leakage may be reduced, compared with the case where the gate inducing layer **109** and the gate dielectric layer **106** directly contact with each other. In addition, when the lanthanum atom-diffused TiN barrier (La-diffused TiN barrier) directly contacts the gate dielectric layer **106**, it is difficult to obtain the low work function of the second gate electrode **110**. Furthermore, in another comparative example, since there is a TiN barrier into which a lanthanum atom is diffused, the gate sheet resistance may be higher than in the case where there is no TiN barrier into which lanthanum atoms are diffused.

As described above, in this embodiment of the present invention, by directly contacting the dipole inducing layer

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109 and the gate dielectric layer 106, not only the gate-induced drain leakage but also the gate sheet resistance may be reduced.

In accordance with an embodiment, the buried gate structure 100G may include a lower buried portion and an upper buried portion. The lower buried portion may include the barrier 107 and the first gate electrode 108. The upper buried portion may include the dipole inducing layer 109, the second gate electrode 110, and the capping layer 111. The upper buried region may overlap with the first and second source/drain regions 112 and 113 horizontally. The lower buried portion may not horizontally overlap with the first and second source/drain regions 112 and 113. The lower buried portion may overlap with the channel CH.

FIG. 3 is a cross-sectional view of a semiconductor device 100' in accordance with an example of an embodiment of the present invention. Some constituent elements of the semiconductor device 100' may be the same as those of the semiconductor device 100 of FIG. 2A. More specifically, the other constituent elements except for a dipole inducing layer 109' may be the same as those of the semiconductor device 100 of FIG. 2A.

Referring to FIG. 3, the semiconductor device 100' may have a buried gate structure 100G'. The buried gate structure 100G' may include a dipole inducing layer 109'. The dipole inducing layer 109' may include an interface portion 109I, a first side portion 109S1', and a second side portion 109S2'. The top surface of the second gate electrode 110 may be lower than the top surface of the first and second side portions 109S1' and 109S2'. The top surfaces of the first and second side portions 109S1' and 109S2' and the top surface of the active region 104 may be at the same level. In this case, the first and second side portions 109S1' and 109S2' may be in direct contact with both sidewalls of the capping layer 111.

The dipole inducing layer 109' may overlap with the first and second source/drain regions 112 and 113 in the horizontal direction (see I-I') with the gate dielectric layer 106 between them. The dipole inducing layer 109' may extend to be positioned between the capping layer 111 and the gate dielectric layer 106 (see II-II'). This may allow the dipole inducing layer 109' to fully overlap with the first and second source/drain regions 112 and 113. The second gate electrode 110 may overlap with the first and second source/drain regions 112 and 113 in the horizontal direction (see I-I') with the dipole inducing layer 109' and the gate dielectric layer 106 interposed between them. The lowest portion of the dipole inducing layer 109' may be at the same level as the lowest portion of the first source/drain region 112 and the second source/drain region 113. The dipole inducing layer 109' may not overlap the channel CH in the horizontal directions.

The dipole inducing layer 109' may be made of the same material as the dipole inducing layer 109 of FIG. 2.

FIGS. 4A to 4H illustrate an example of a method for fabricating the semiconductor device 100 shown in FIGS. 2A and 2B.

Referring to FIG. 4A, an isolation layer 12 may be formed over the substrate 11. An active region 14 may be defined by the isolation layer 12. The isolation layer 12 may be formed by a Shallow Trench Isolation (STI) process. For example, the substrate 11 may be etched to form the isolation trench 13. The isolation trench 13 may be filled with a dielectric material, and thus an isolation layer 12 may be formed. The isolation layer 12 may include a silicon oxide, a silicon nitride, or a combination thereof. Chemical Vapor Deposition (CVD) process or other deposition processes may be

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used to fill the isolation trench 13 with a dielectric material. A planarization process such as Chemical-Mechanical Polishing (CMP) may be additionally performed for removing excess dielectric material from the isolation trench and creating a flat polished top surface for the isolation layer 12

A gate trench 15 may be formed in the substrate 11. The gate trench 15 may be formed in the shape of a line traversing the active region 14 and the isolation layer 12. In an embodiment, the gate trench 15 may be formed by using a hard mask HM as an etch mask and performing an etching process. The hard mask HM may be formed over the substrate 11 and may have a line-shaped opening. The hard mask HM may be formed of a material having an etch selectivity with respect to the substrate 11. For example, in an embodiment, the hard mask HM may be a silicon oxide such as TEOS (Tetra-Ethyl-Ortho-Silicate). The gate trench 15 may be formed shallower than the isolation trench 13. The gate trench 15 may have sufficient depth to increase the average cross-sectional area of the subsequent gate electrode. Thus, the resistance of the gate electrode may be reduced. The bottom portion of the gate trench 15 may have a curvature. By forming the trenches to have the curvature, the gate trenches 15 may be filled more readily with the various materials. Also, the curvature may contribute in the alleviation of an electric field at the bottom edge of the gate trench 16.

Subsequently, the fin region 14F may be formed. For forming the fin region 14F, the isolation layer 12 below the gate trench 15 may be recessed. As for the fin region 14F, the fin region 104F of FIG. 2B will be referred to.

A gate dielectric layer 16 may be formed on the surface of the gate trench 15 and the hard mask HM, as shown in FIG. 4B. The etch damage of the surface of the gate trench 15 may be corrected before the gate dielectric layer 16 is formed. For example, after a sacrificial oxide is formed by a thermal oxidation treatment, the sacrificial oxide may be removed.

The gate dielectric layer 16 may be formed by a thermal oxidation process. In accordance with an embodiment, the gate dielectric layer 16 may be formed by Chemical Vapor Deposition (CVD) or Atomic Layer Deposition (ALD). The gate dielectric layer 16 may include a high dielectric material, an oxide, a nitride, an oxynitride, or a combination thereof. The high dielectric material may include a hafnium-containing material. The hafnium-containing material may include a hafnium oxide, a hafnium silicon oxide, a hafnium silicon oxynitride, or a combination thereof. In accordance with an embodiment, the high-k material may include a lanthanum oxide, a lanthanum aluminum oxide, a zirconium oxide, a zirconium silicon oxide, a zirconium silicon oxynitride, an aluminum oxide, or a combination thereof. As for the high-dielectric material, other high-k materials known in the art may be optionally used. The gate dielectric layer 16 may include a material having a high oxygen atom areal density.

A barrier layer 17A may be formed over the gate dielectric layer 16. The barrier layer 17A may be conformally formed on the surface of the gate dielectric layer 16. The barrier layer 17A may include a metal-based material. The barrier layer 17A may include a metal nitride. The barrier layer 17A may include a titanium nitride or a tantalum nitride. The barrier layer 17A may be formed by performing an Atomic Layer Deposition (ALD) process or a Chemical Vapor Deposition (CVD) process.

A first conductive layer 18A may be formed over the barrier layer 17A. The first conductive layer 18A may fill the gate trench 15. The first conductive layer 18A may include

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a low resistance metal material. The first conductive layer **18A** may include tungsten. The first conductive layer **18A** may be formed by a CVD process or an ALD process.

Referring to FIG. 4C, a barrier **17** and a first gate electrode **18** may be formed in the gate trench **15**. For forming the barrier **17** and the first gate electrode **18**, a recessing process may be performed. The recessing process may include a dry etching process, for example, an etch-back process. The barrier **17** may be formed by an etch-back process of the barrier layer **17A**. The first gate electrode **18** may be formed by an etch-back process of the first conductive layer **18A**. In accordance with an embodiment, the recessing process may include first performing a planarization process for exposing a top surface of the hard mask HM, and then performing an etch-back process following the planarization process. For example, the planarization process may be a chemical mechanical polishing. The top surfaces of the barrier **17** and the first gate electrode **18** may be positioned at the same level.

The top surfaces of the barrier **17** and the first gate electrode **18** may be formed to be lower than the top surface of the active region **14**. The barrier **17** and the first gate electrode **18** may also be referred to herein as ‘a lower conductive layer or a lower buried portion’.

Referring to FIG. 4D, a dipole inducing material **19A** may be formed over the top surfaces of the barrier **17** and the first gate electrode **18** and also over the exposed surface of the gate dielectric layer **16**. The dipole inducing material **19A** may be formed conformally over the aforementioned surfaces. In an embodiment, the dipole inducing material **19A** may be formed by performing an atomic layer deposition (ALD) process or a chemical vapor deposition (CVD) process. The thickness of the dipole inducing material **19A** may be sufficiently thin for an effective electrical connection between the subsequent first gate electrode and the second gate electrode. The thickness of the dipole inducing material **19A** may be thinner than the thickness of the gate dielectric layer **16**. Preferably, the dipole inducing material **19A** may have a thickness of approximately 10 Å or less. More preferably, the dipole inducing material **19A** may have a thickness of approximately 1 to 10 Å. The dipole inducing material **19A** may be a monolayer. The dipole inductive material **19A** and the gate dielectric layer **16** may form a dipole for adequately reducing an effective work function of the second gate electrode **20**. In an embodiment, the dipole inducing material **19A** may be a metal oxide or a metal oxide monolayer. The dipole inducing material **19A** may include a lanthanum oxide (La₂O₃) or a lanthanum oxide monolayer. In accordance with an embodiment, the dipole inducing material **19A** may include a yttrium oxide (Y₂O₃), a germanium oxide (GeO₂), a lutetium oxide (Lu₂O₃), or a strontium oxide (SrO). The dipole inductive material **19A** may include a material having a lower oxygen atom areal density than the gate dielectric layer **16**. Thus, the dipole inducing material **19A** and the gate dielectric layer **16** may induce a dipole that reduces a work function.

A second conductive layer **20A** may be formed over the dipole inducing material **19A**. The second conductive layer **20A** may fill the remaining space of the gate trench **15**. The second conductive layer **20A** may include a low-resistance metal material. The second conductive layer **20A** may comprise a titanium nitride. The second conductive layer **20A** may be formed by a chemical vapor deposition (CVD) process or an atomic layer deposition (ALD) process. The first gate electrode **18** and the second conductive layer **20A** may be made of the same material. In accordance with an embodiment, the first gate electrode **18** and the second

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conductive layer **20A** may be formed of different materials. The first gate electrode **18** and the second conductive layer **20A** may be formed of a low-resistance material to lower the gate-sheet resistance.

Referring to FIG. 4E, the second gate electrode **20** may be formed inside the gate trench **15**. For forming the second gate electrode **20**, a recessing process may be performed. The recessing process may include performing dry etching, for example, an etch-back process. The second gate electrode **20** may be formed by an etch-back process of the second conductive layer **20A**. In accordance with an embodiment, the recessing process may include first performing a planarization process for exposing the hard mask HM, and then performing an etch-back process following the planarization process. The planarization process may be any suitable planarization process including but not limited to a chemical mechanical polishing. The top surface of the second gate electrode **20** may be recessed lower than the top surface of the active region **14**.

Referring to FIG. 4F, a dipole inducing layer **19** may be formed inside the gate trench **15**. For forming the dipole inducing layer **19**, a recessing process may be performed. The recessing process may include performing dry etching, for example, an etch-back process. The dipole inducing layer **19** may be formed by an etch-back process of the dipole inducing material **19A**. In accordance with an embodiment, the recessing process may include first performing a planarization process for exposing the hard mask HM, and then performing an etch-back process following the planarization process. The top surfaces of the dipole inducing layer **19** and the second gate electrode **20** may be positioned at the same level. The top surface of the dipole inducing layer **19** may be recessed lower than the top surface of the active region **14**. In accordance with an embodiment, the recessing process of the dipole inducing material **19A** may include performing wet etching. For example, the wet etching may be performed by a mixture of HCl/HF.

The dipole inducing layer **19** may include an interface portion **191**, a first side portion **19S1**, and a second side portion **19S2**. The first and second side portions **19S1** and **19S2** may have a shape extending vertically upwards from the interface portion **191**. The interface portion **191** may be positioned between and be in direct contact with the first gate electrode **18** and the second gate electrode **20**. The interface portion **191** may be coupled to the top surface of the barrier **17**. The top surfaces of the first and second side portions **19S1** and **19S2** may be positioned at a lower level than the top surface of the substrate **11**. The top surfaces of the first and second side portions **19S1** and **19S2** may be positioned at the same level as the top surface of the second gate electrode **20**. The dipole inducing layer **19** may be formed to be in direct contact with the second gate electrode **20** and the gate dielectric layer **16**.

The dipole inducing layer **19** and the second gate electrode **20** may be referred to also herein as ‘an upper conductive layer or an upper buried portion’.

Referring to FIG. 4G, a capping layer **21** is formed on the dipole inducing layer **19** and the second gate electrode **20**. The capping layer **21** may fill the remaining of the gate trench **15**. Subsequently, the capping layer **21** may be planarized so that a top surface of the hard mask HM is exposed. During the planarization process or after the planarization process of the capping layer **21**, the gate dielectric layer **16** which extended on the top surface of the hard mask HM may be removed. The gate dielectric layer **16** may remain in the gate trench **15**. The capping layer **21** may be formed of any suitable dielectric material. For example, the

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capping layer **21** may include a silicon nitride. In an embodiment, the capping layer **21** may have an ONO (Oxide-Nitride-Oxide) structure.

Through the above-described processes, the buried gate structure may be formed. The buried gate structure may include the gate dielectric layer **16**, the barrier **17**, the first gate electrode **18**, the dipole inducing layer **19**, the second gate electrode **20** and the capping layer **21**. The top surface of the second gate electrode **20** may be positioned lower than the top surface of the active region **14**. Thus, as the top surface of the second gate electrode **20** is physically recessed, an effective physical distance between the second gate electrode **20** and the surrounding conductive material (e.g., a contact plug) may be sufficiently secured.

After the capping layer **21** is formed, as illustrated in FIG. 4H, a doping process of doping an impurity may be performed by an implantation or other doping techniques. Thus, a first source/drain region **22** and a second source/drain region **23** may be formed in the substrate **11**. The first source/drain region **22** and the second source/drain region **23** may overlap with the second gate electrode **20** and the dipole inducing layer **19** in the horizontal direction. The dipole inductive layer **19** may overlap horizontally (see I-I') with the first and second source/drain regions **22** and **23**. The barrier **17** and the first gate electrode **18** may not horizontally overlap (see I-I') with the first and second source/drain regions **22** and **23**. The lowest portion of the dipole inducing layer **19** may be at the same level as the lowest portion of the first source/drain region **22** and the second source/drain region **23**.

As described above, since the dipole inducing layer **19** and the gate dielectric layer **16** are in direct contact with each other, gate-induced drain leakage may be suppressed substantially.

In a comparative example, the dipole inducing material **19A** is etched back before forming the second conductive layer **20A**. This allows the dipole inductive layer **19** to remain in the form of a spacer on the sidewalls of the gate dielectric layer **16** and subsequently form the second gate electrode **20** by depositing the second conductive layer **20A** and performing an etch-back process. However, this process of the comparative example may damage the underlying first gate electrode **18** during the etch-back process of the dipole inducing material **19A**. In addition, in the process of the comparative example, the height of the dipole inducing layer **19** may not be adjusted.

FIGS. 5A to 5C illustrate an example of a method for fabricating the semiconductor device **100'** shown in FIG. 3.

First, a dipole inducing material **19A** and a second conductive layer **20A** may be formed by the method described in FIGS. 4A to 4D.

Subsequently, as shown in FIG. 5A, a second gate electrode **20'** that is planarized in the gate trench **15** may be formed. For forming the planarized second gate electrode **20'**, a planarization process such as a chemical mechanical polishing may be performed. The planarization process may expose the top surface of the hard mask HM. Therefore, the top surface of the planarized second gate electrode **20'** may be positioned at the same level as the top surface of the hard mask HM.

Subsequently, the dipole inducing layer **19'** may be formed in the gate trench **15**. To form the dipole inducing layer **19'**, a chemical mechanical polishing may be performed. The chemical mechanical polishing may be performed such that the top surface of the hard mask HM is

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exposed. Thus, the top surface of the dipole inducing layer **19'** may be positioned at the same level as the top surface of the hard mask HM.

Referring to FIG. 5B, a second gate electrode **20** may be formed in the gate trench **15**. For forming the second gate electrode **20**, a recessing process of the planarized second gate electrode **20'** may be performed. The recessing process may include performing dry etching, for example, an etch-back process. The top surface of the dipole inducing layer **19'** and the second gate electrode **20** may be positioned at different levels. The top surface of the dipole inducing layer **19'** may be positioned higher than the top surface of the active region **14**, and the top surface of the second gate electrode **20** may be positioned lower than the active region **14**.

The height of the dipole inducing layer **19'** may be different from the height of the dipole inducing layer **19** of FIG. 4H. For example, the uppermost surface of the dipole inducing layer **19'** may be positioned at a higher level than the top surface of the dipole inducing layer **19** of FIG. 4H.

Referring to FIG. 5C, a capping layer **21** may be formed over the dipole inducing layer **19'** and the second gate electrode **20**. Subsequently, the capping layer **21** may be planarized to expose the top surface of the hard mask HM. The capping layer **21** may include any suitable dielectric material. For example, the capping layer **21** may include a silicon nitride. In an embodiment, the capping layer **21** may have an ONO (Oxide-Nitride-Oxide) structure.

Through the above-described processes, a buried gate structure may be formed. The buried gate structure may include the gate dielectric layer **16**, the barrier **17**, the first gate electrode **18**, the dipole inducing layer **19'**, the second gate electrode **20** and the capping layer **21**. The top surface of the second gate electrode **20** may be positioned lower than the top surface of the substrate **11**.

After the capping layer **21** is formed, a first source/drain region **22** and a second source/drain region **23** may be formed in the active region **14**. The dipole inducing layer **19'** may fully overlap with the first and second source/drain regions **22** and **23** horizontally (see I-I'). The barrier **17** and the first gate electrode **18** may not overlap with the first and second source/drain regions **22** and **23**.

The dipole inducing layer **19'** and the gate dielectric layer **16** may be positioned between the capping layer **21** and the first and second source/drain regions **22** and **23** (see II-II'). The dipole inducing layer **19'** and the gate dielectric layer **16** may be positioned between the second gate electrode **20** and the first and second source/drain regions **22** and **23** (see I-I'). The dipole inducing layer **19'** may be positioned between and be in direct contact with the first gate electrode **18** and the second gate electrode **20**. The dipole inducing layer **19'** may be positioned between the second gate electrode **20** and the gate dielectric layer **16**.

FIG. 6 is a cross-sectional view illustrating a semiconductor device **120** in accordance with a second embodiment of the present invention. Some constituent elements of the semiconductor device **120** may be the same as those of the semiconductor device **100** shown in FIG. 2A. More specifically, the other constituent elements except for an anti-oxidation barrier **121** may be the same as those of the semiconductor device **100** shown in FIG. 2A.

Referring to FIG. 6, the semiconductor device **120** may include a buried gate structure **120G**. The buried gate structure **120G** may include a gate dielectric layer **106**, a barrier **107**, a first gate electrode **108**, an anti-oxidation barrier **121**, a dipole inducing layer **109**, a second gate electrode **110**, and a capping layer **111**. The anti-oxidation

barrier **121** may be positioned between and be in direct contact with the first gate electrode **108** and the dipole inducing layer **109**. A portion of the anti-oxidation barrier **121** may be extended to be positioned between the barrier **107** and the dipole inducing layer **109**. The anti-oxidation barrier **121** may prevent the first gate electrode **108** from being oxidized. For example, the top surface of the first gate electrode **108** may be prevented from being oxidized during the formation of the dipole inducing layer **109**.

The anti-oxidation barrier **121** may include a conductive material. The anti-oxidation barrier **121** may be a metal-based material for the buried gate structure **120G** to have a low resistance. The anti-oxidation barrier **121** may be of a metal nitride. For example, the anti-oxidation barrier **121** may be formed of a titanium nitride. The barrier **107** and the anti-oxidation barrier **121** may be made of the same material.

The anti-oxidation barrier **121** may not horizontally overlap with the first and second source/drain regions **112** and **113**. For example, the anti-oxidation barrier **121** may not be extended to the interface between the dipole inducing layer **109** and the gate dielectric layer **106**.

FIGS. 7A to 7E illustrate an example of a method for fabricating the semiconductor device **120** shown in FIG. 6.

First, a barrier **17** and a first gate electrode **18** may be formed in a gate trench **15** by the method described in FIGS. 4A to 4C.

Subsequently, referring to FIG. 7A, an anti-oxidation layer **31A** may be formed over the barrier **17** and the first gate electrode **18**. The anti-oxidation layer **31A** may include a material for preventing the oxidation of the first gate electrode **18**. The anti-oxidation layer **31A** may include a metal-based material. The anti-oxidation layer **31A** may be formed of a metal nitride. The anti-oxidation layer **31A** may be formed of a titanium nitride. An anti-oxidation layer **31A** may be formed over the barrier **17**, the first gate electrode **18**, and the gate dielectric layer **16**.

The anti-oxidation layer **31A** may be deposited by a physical vapor deposition (PVD) process. Accordingly, the anti-oxidation layer **31A** may be non-conformally deposited. For example, the thickness deposited over a flat surface (hereinafter, which will be denoted by 'D1') may be thicker than the thickness deposited over a vertical surface (hereinafter, which will be denoted by 'D1').

The thickness D1 deposited over the barrier **17** and the first gate electrode **18** may be thicker than the thickness D2 deposited over the gate dielectric layer **16** of the sidewall of the gate trench **15**. The thickness D1 deposited over the gate dielectric layer **16** over the hard mask HM may also be thicker than the thickness D2 deposited over the gate dielectric layer **16** of the sidewall of the gate trench **15**. The anti-oxidation layer **31A** may be of the same thickness over the barrier **17**, the first gate electrode **18** and the hard mask HM.

Referring to FIG. 7B, the anti-oxidation barrier **31** may be formed. The anti-oxidation barrier **31** may be formed by selectively etching the anti-oxidation layer **31A**. The anti-oxidation barrier **31** may be positioned over the barrier **17** and the first gate electrode **18**. The anti-oxidation layer **31A** may be etched back to form the oxidation preventing barrier **31**. The dummy anti-oxidation layer **31D** may remain over the gate dielectric layer **16** over the hard mask HM. The anti-oxidation barrier **31** and the dummy anti-oxidation layer **31D** may be discontinuous. The anti-oxidation layer may not remain on the sidewall of the upper portion of the gate trench **15**.

Referring to FIG. 7C, a dipole inducing material **19A** may be formed. The dipole inducing material **19A** may be conformally formed on the anti-oxidation barrier **31** and the gate dielectric layer **16**.

A second conductive layer **20A** may be formed over the dipole inducing material **19A**. The second conductive layer **20A** may fill the gate trench **15**. The second conductive layer **20A** may include any suitable low-resistance metal material. For example, the second conductive layer **20A** may include a titanium nitride. The second conductive layer **20A** may be formed by a Chemical Vapor Deposition (CVD) process or an Atomic Layer Deposition (ALD) process.

The dipole inducing material **19A** and the second conductive layer **20A** may be the same as the dipole inducing material **19A** and the second conductive layer **20A** of FIG. 4D.

Referring to FIG. 7D, the second gate electrode **20** may be formed in the gate trench **15**. For forming the second gate electrode **20**, a recessing process may be performed. The recessing process may include performing dry etching, for example, an etch-back process. The second gate electrode **20** may be formed by an etch-back process of the second conductive layer **20A**. In accordance with an embodiment, the recessing process may include first performing a planarization process for exposing the hard mask HM, and then performing an etch-back process following the planarization process. The planarization process may be any suitable planarization process including but not limited to a chemical mechanical polishing. The top surface of the second gate electrode **20** may be recessed lower than the top surface of the active region **14**. The dummy anti-oxidation layer **31D** may be removed during the etch-back process of the second conductive layer **20A**.

Subsequently, the dipole inducing layer **19** may be formed in the gate trench **15**. For forming the dipole inducing layer **19**, a recessing process may be performed. The recessing process may include performing dry etching, for example, an etch-back process. The dipole inducing layer **19** may be formed by an etch-back process of the dipole inducing material **19A**. In accordance with an embodiment, the recessing process may include first performing a planarization process for exposing the hard mask HM, and then performing an etch-back process following the planarization process. The top surfaces of the dipole inducing layer **19** and the second gate electrode **20** may be positioned at the same level. The top surface of the dipole inducing layer **19** may be recessed lower than the top surface of the active region **14**. In accordance with an embodiment, the recessing process of the dipole inducing material **19A** may include performing wet etching. For example, the wet etching may be performed by a mixture of HCl/HF. The dipole inducing layer **19** may be positioned at the same as the dipole inducing layer **19** of FIG. 4F. For example, referring back to FIG. 4F, the dipole inducing layer **19** may include an interface portion **191**, a first side portion **19S1**, and a second side portion **19S2**. The first and second side portions **19S1** and **19S2** may extend vertically from the ends of the horizontal interface portion **191**. The interface portion **191** may be positioned between and be in direct contact with the first gate electrode **18** and the second gate electrode **20**.

Referring to FIG. 7E, the capping layer **21** may be formed over the dipole inducing layer **19** and the second gate electrode **20**. Subsequently, the capping layer **21** may be planarized so as for exposing the top surface of the hard mask HM. During the planarization process of the capping layer **21** or after the planarization process of the capping layer **21**, the gate dielectric layer **16** on the top surface of the

hard mask HM may be removed. The capping layer **21** may include any suitable dielectric material. For example, the capping layer **21** may include a silicon nitride. In an embodiment, the capping layer **21** may have a structure of ONO (Oxide-Nitride-Oxide).

Through the processes described above, a buried gate structure may be formed. The buried gate structure may include the gate dielectric layer **16**, the barrier **17**, the first gate electrode **18**, the anti-oxidation barrier **31**, the dipole inducing layer **19**, the second gate electrode **20**, and a capping layer **21**. The top surface of the second gate electrode **20** may be positioned lower than the top surface of the substrate **11**.

After the capping layer **21** is formed, a first source/drain region **22** and a second source/drain region **23** may be formed in the active region **14**. The anti-oxidation barrier **31** may not horizontally overlap with the first and second source/drain regions **22** and **23**. The dipole inducing layer **19** may be positioned between the anti-oxidation barrier **31** and the second gate electrode **20**. The dipole inducing layer **19** may be positioned between the second gate electrode **20** and the gate dielectric layer **16**.

FIG. **8A** is a cross-sectional view illustrating a semiconductor device **200** in accordance with a third embodiment of the present invention. Some constituent elements of the semiconductor device **200** may be the same as those of the semiconductor device **100** of FIG. **2A**. More specifically, the other constituent elements except for a first gate electrode **210** may be the same as those of the semiconductor device **100** of FIG. **2A**.

Referring to FIG. **8A**, the semiconductor device **200** may include a buried gate structure **200G**. The buried gate structure **200G** may include a gate dielectric layer **106**, a first gate electrode **210**, a dipole inducing layer **109**, a second gate electrode **110**, and a capping layer **111**. The first gate electrode **210** may be formed of a material that does not attack the gate dielectric layer **106**. For example, the first gate electrode **210** may be formed of a material that does not contain any impurity, e.g., fluorine, i.e., a fluorine-free material. Thus, the barrier between the first gate electrode **210** and the gate dielectric layer **106** may be omitted. The first gate electrode **210** may include a titanium nitride. Since the first gate electrode **210** includes a fluorine-free material, the first gate electrode **210** may be referred to also herein as 'a barrier-less gate electrode'. The first gate electrode **108** of FIG. **2A** may be referred to also herein as 'a barrier-included gate electrode' which requires a barrier **107**. The first gate electrode **108** of FIG. **2A** may include tungsten, and the first gate electrode **210** of FIG. **8A** may include a titanium nitride. The titanium nitride may not attack the gate dielectric layer **106**. Since the barrier is omitted, the filling characteristics of the first gate electrode **210** may be improved, and the gate sheet resistance may be further reduced.

The first gate electrode **210** and the second gate electrode **110** may be made of the same material. For example, the first gate electrode **210** and the second gate electrode **110** may each be formed of a titanium nitride. Accordingly, the first gate electrode **210** and the second gate electrode **110** may become a 'TiN-Only' gate electrode. The dipole inducing layer **109** may be positioned between and be in direct contact with the first gate electrode **210** and the second gate electrode **110**. In an example the structure of the first gate electrode **210**/the dipole inducing layer **109**/the second gate electrode **110** may be formed of TiN/La₂O₃/TiN.

The top surface of the dipole inducing layer **109** may be positioned at a lower level than the top surface of the substrate **101**. In accordance with an embodiment, the top

surface of the dipole inducing layer **109** may be positioned at the same level as the top surface of the substrate **101**, as shown in FIG. **3**.

FIG. **8B** is a cross-sectional view illustrating a semiconductor device **200'** in accordance with a fourth embodiment of the present invention. Some constituent elements of the semiconductor device **200'** may be the same as those of the semiconductor device **200** of FIG. **8A**. More specifically, the other constituent elements except for a second gate electrode **220** may be the same as those of the semiconductor device **200** of FIG. **8A**.

Referring to FIG. **8B**, the semiconductor device **200'** may include a buried gate structure **200G'**. The buried gate structure **200G'** may include a gate dielectric layer **106**, a first gate electrode **210**, a dipole inducing layer **109**, a second gate electrode **220**, and a capping layer **111**.

The first gate electrode **210** may be formed of a material that does not attack the gate dielectric layer **106**. For example, the first gate electrode **210** may be formed of a material that does not contain any impurity, e.g., fluorine, i.e., a fluorine-free material. The first gate electrode **210** may comprise a titanium nitride.

The first gate electrode **210** and the second gate electrode **220** may be formed of different materials. For example, the second gate electrode **220** may be formed of polysilicon. The second gate electrode **220** may be formed of polysilicon having a low work function. The second gate electrode **220** may be formed of polysilicon doped with an N-type impurity (hereinafter, which will be referred to as an N-type polysilicon). When the N-type polysilicon is applied as the second gate electrode **220**, the agglomeration issues may be improved. The second gate electrode **220** may include N⁺ polysilicon (N⁺ poly Si) doped with a high-concentration N-type impurity. The N-type impurity may include, for example, phosphorus (P) or arsenic (As).

In an embodiment, the first gate electrode **210** may be formed of a titanium nitride and the second gate electrode may be formed of an N-type polysilicon. The dipole inducing layer **109** may be positioned between and be in direct contact with both the first gate electrode **210** and the second gate electrode **220**.

The top surface of the dipole inducing layer **109** may be positioned at a lower level than the top surface of the substrate **101**. In accordance with an embodiment, the top surface of the dipole inducing layer **109** may be positioned at the same level as the top surface of the substrate **101**, as shown in FIG. **3**.

The gate-induced drain leakage may be further suppressed by the dipole inducing layer **109** and the second gate electrode **220**. For example, since the second gate electrode **220** has a low work function and the work function of the second gate electrode **220** is lowered by the dipole inducing layer **109** and the gate dielectric layer **106**, the gate-induced drain leakage may be further suppressed.

FIGS. **9A** to **9E** illustrate an example of a method for fabricating the semiconductor device **200** shown in FIG. **8A**.

Referring to FIG. **9A**, an isolation layer **12** may be formed over a substrate **11** to define an active region **14**. The isolation layer **12** may be formed inside an isolation trench **13**.

A gate trench **15** may be formed in the substrate **11**. The gate trench **15** may be formed in the shape of a line traversing the active region **14** and the isolation layer **12**. In an embodiment, the gate trench **15** may be formed by using a hard mask HM as an etch mask and performing an etch process.

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Subsequently, a fin region **14F** may be formed. For forming the fin region **14F**, the isolation layer **12** below the gate trench **15** may be recessed.

Subsequently, a gate dielectric layer **16** may be formed over the surfaces of the gate trench **15** and the hard mask **5** **HM**. The gate dielectric layer **16** may be made of any suitable high-k material, an oxide, a nitride, an oxynitride, or a combination thereof.

A first conductive layer **41A** may be formed over the gate dielectric layer **16** to fill the remainder of the gate trench **15**. **10** The first conductive layer **41A** may be made of any suitable low-resistance metal material. The first conductive layer **41A** may include a metal material that does not contain any impurities such as fluorine. In an embodiment, the first conductive layer **41A** may include a titanium nitride. **15** The first conductive layer **41A** may be formed by a Chemical Vapor Deposition (CVD) process or an Atomic Layer Deposition (ALD) process. In accordance with an embodiment, the first conductive layer **41A** may be a fluorine-free tungsten layer (fluorine-free **W**).

Referring to FIG. **9B**, a first gate electrode **41** may be formed in the gate trench **15**. For forming the first gate electrode **41**, a recessing process may be performed. The recessing process may include performing dry etching, for example, an etch-back process. The first gate electrode **41** **25** may be formed by an etch-back process of the first conductive layer **41A**. In accordance with an embodiment, the recessing process may include first performing a planarization process for exposing the top surface of the hard mask **HM**, and then performing an etch-back process following the planarization process. **30** The planarization process may be any suitable planarization process including but not limited to a chemical mechanical polishing. The top surface of the first gate electrode **41** may be recessed lower than the top surface of the active region **14**.

Referring to FIG. **9C**, a dipole inducing material **19A** may be formed over the first gate electrode **41** and the gate dielectric layer **16**. The dipole inducing material may be formed conformally with the internal walls of the gate trench **15**.

A second conductive layer **20A** may be formed over the dipole inducing material **19A**. The second conductive layer **20A** may fill the gate trench **15**. The second conductive layer **20A** may include any suitable low-resistance metal material. For example, the second conductive layer **20A** may include **45** a titanium nitride. The second conductive layer **20A** may be formed by a Chemical Vapor Deposition (CVD) process or an Atomic Layer Deposition (ALD) process.

The dipole inducing material **19A** and the second conductive layer **20A** may be formed of the same material as the dipole inducing material **19A** and the second conductive layer **20A** of FIG. **4D**.

In accordance with an embodiment, a suitable material for the second conductive layer **20A** may include an N-type polysilicon. Thus, following the aforementioned steps the second gate electrode **220** of the semiconductor device **200'** shown in FIG. **8B** may be formed.

Referring to FIG. **9D**, a second gate electrode **20** may be formed in the gate trench **15**. For forming the second gate electrode **20**, a recessing process may be performed. The recessing process may include performing dry etching, for example, an etch-back process. The second gate electrode **20** may be formed by an etch-back process of the second conductive layer **20A**. In accordance with an embodiment, the recessing process may include first performing a planarization process for exposing the hard mask **HM**, and then performing an etch-back process following the planarization

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process. The planarization process may be any suitable planarization process including but not limited to a chemical mechanical polishing. The top surface of the second gate electrode **20** may be recessed lower than the top surface of the active region **14**.

Subsequently, a dipole inducing layer **19** may be formed in the gate trench **15**. For forming the dipole inducing layer **19**, a recessing process may be performed. The recessing process may include performing dry etching, for example, an etch-back process. The dipole inducing layer **19** may be formed by an etch-back process of the dipole inducing material **19A**. In accordance with an embodiment, the recessing process may include first performing a planarization process for exposing the hard mask **HM**, and then performing an etch-back process following the planarization process. The planarization process may be any suitable planarization process including but not limited to a chemical mechanical polishing. In accordance with an embodiment, the recessing process of the dipole inducing material **19A** **20** may include performing wet etching. For example, the wet etching may be performed by a mixture of HCl/HF. The top surfaces of the dipole inducing layer **19** and the second gate electrode **20** may be positioned at the same level. The top surface of the dipole inducing layer **19** may be recessed lower than the top surface of the active region **14**. The dipole inducing layer **19** may be the same as the dipole inducing layer **19** of FIG. **4F**. For example, the dipole inducing layer **19** may include an interface portion **191**, a first side portion **19S1**, and a second side portion **19S2**. The first and second side portions **19S1** and **19S2** may extend vertically from the ends of the horizontal interface portion **191**. The interface portion **191** may be positioned between and be in direct contact with the first gate electrode **18** and the second gate electrode **20**.

Referring to FIG. **9E**, a capping layer **21** may be formed over the dipole inducing layer **19** and the second gate electrode **20** and may fill the remainder of the gate trench **15**.

After the capping layer **21** is formed, a first source/drain region **22** and a second source/drain region **23** may be formed in the active region **14**. The dipole inducing layer **19** **40** may horizontally overlap with the first and second source/drain regions **22** and **23** (see I-I').

In the above-described embodiments of the present invention, the dipole inducing layer **109**, **109'**, **19** and **19'** may be formed to have a predetermined thickness. In the following embodiments of the present invention, the buried gate structure may include a dipole inducing portion that is locally positioned in the gate dielectric layer. The dipole inducing portion may include diffused dipole chemical species.

FIG. **10A** is a cross-sectional view illustrating a semiconductor device **300** in accordance with a fifth embodiment of the present invention. FIG. **10B** is a magnified view of a dipole inducing portion shown in FIG. **10A**. Some constituent elements of the semiconductor device **300** may be the same as those of the semiconductor device **100** of FIG. **2A**. More specifically, the constituent elements other than the dipole inducing portion **309** and the second gate electrode **310** may be similar to the semiconductor device **100** of FIG. **2A**.

Referring to FIGS. **10A** and **10B**, the semiconductor device **300** may include a buried gate structure **300G**. The buried gate structure **300G** may include a gate dielectric layer **106**, a barrier **107**, a first gate electrode **108**, a dipole inducing portion **309**, a second gate electrode **310**, and a capping layer **111**. The semiconductor device **300** may further include first and second source/drain regions **112** and **113**.

The dipole inducing portion 309 may be positioned between the second gate electrode 310 and the gate dielectric layer 106. Unlike, the aforementioned embodiments of the invention, in the embodiment of FIG. 10A, the dipole inducing portion 309 may not be positioned between the first gate electrode 108 and the second gate electrode 110. Also, the dipole inducing portion 309 may not be positioned between the barrier 107 and the second gate electrode 310. The first gate electrode 108 and the barrier 107 may be in direct contact with the second gate electrode 310. The dipole inducing portion 309 may include a plurality of DICS.

The dipole inducing portion 309 may be locally positioned in the gate dielectric layer 106. In other words, the dipole inducing portion 309 may be positioned in the gate dielectric layer 106. The gate dielectric layer 106 may include a first portion 106A and a second portion 106B. The second portion 106B may include a dipole inducing portion 309, and the first portion 106A may not include the dipole inducing portion 309. The upper portion of the second portion 106B may be thinner than the first portion 106A ($D1 > D2$). The first portion 106A and the second portion 106B may be one continuous layer. The first portion 106A and the second portion 106B may be made of the same material. The second gate electrode 310 may have a wider width than the first gate electrode 108.

The second portion 106B of the gate dielectric layer 106 may include a third portion 106C and a fourth portion 106D. The dipole inducing portion 309 may be included in the third portion 106C, and the dipole inducing portion 309 may not be included in the fourth portion 106D. The third portion 106C may be in direct contact with the second gate electrode 310. The fourth portion 106D may be in direct contact with the first and second source/drain regions 112 and 113. The dipole inducing portion 309 may be diffused and positioned in the third portion 106C.

The first portion 106A and the fourth portion 106D of the gate dielectric layer 106 may be of a silicon oxide. The third portion 106C of the gate dielectric layer 106 may be of a silicon oxide containing the dipole inducing portion 309. The third portion 106C of the gate dielectric layer 106 may be of a lanthanum-diffused silicon oxide (La diffused SiO_2). The lanthanum-diffused silicon oxide (La diffused SiO_2) may be referred to also herein as 'a lanthanum silicate'.

The dipole inducing portion 309 may overlap with the first and second source/drain regions 112 and 113 in the horizontal direction (see I-I'). The lowest portion of the third portion 106C of the gate dielectric layer 106 may be positioned at the same level as the lowest portion of the first and second source/drain regions 112 and 113. The dipole inducing portion 309 may not be positioned between the first gate electrode 108 and a channel CH.

Since the dipole inducing portion 309 is positioned in the gate dielectric layer 106, the filling characteristics of the second gate electrode 310 may be improved. The dipole may be induced in the gate dielectric layer 106 by the dipole inducing portion 309. Therefore, the suppression of the gate-induced drain leakage (GIDL) may be improved.

FIG. 11A is a cross-sectional view illustrating a semiconductor device 300' in accordance with a sixth embodiment of the present invention. FIG. 11B is a magnified view of a dipole inducing portion. Some constituent elements of the semiconductor device 300' may be the same as those of the semiconductor device 300 of FIG. 10A. More specifically, the constituent elements other than the second gate electrode 310 and the dipole inducing portion 309' may be the same as those of the semiconductor device 300 of FIG. 10A.

Referring to FIGS. 11A and 11B, the semiconductor device 300' may include a buried gate structure 300G'. The buried gate structure 300G' may include a gate dielectric layer 106, a barrier 107, a first gate electrode 108, a dipole inducing portion 309', a second gate electrode 310, and a capping layer 111.

The dipole inducing portion 309' may be positioned between the second gate electrode 310 and the gate dielectric layer 106. The dipole inducing portion 309' may not be positioned between the first gate electrode 108 and the second gate electrode 310. The dipole inducing portion 309' may not be positioned between the barrier 107 and the second gate electrode 310. The first gate electrode 108 and the barrier 107 may be in direct contact with the second gate electrode 310.

The dipole inducing portion 309' may be locally positioned in the gate dielectric layer 106. In other words, the dipole inducing portion 309' may be positioned in the gate dielectric layer 106.

The dipole inducing portion 309' may be contained in the third portion 106C' of the gate dielectric layer 106. The thickness of the third portion 106C' of the gate dielectric layer 106 may be thinner than the thickness of the third portion 106C of FIG. 10A ($W2 < W1$). The width of the second gate electrode 310 may be wider than the width of the second gate electrode 310 of FIG. 10A ($W4 > W3$). As a result, the volume of the second gate electrode 310, which is a low-resistance material, increases, and the gate sheet resistance may be further reduced. In addition, the filling characteristics of the second gate electrode 310 may be further improved.

The dipole inducing portion 309 and 309' of FIGS. 10A and 11A may be formed, as DICS diffuse from the dipole inducing source layer. This will be described later. The dipole inducing source layer may contain DICS. For example, a dipole inducing source layer deposition process, a heat treatment, and a dipole inducing source layer removing process may be performed for diffusing the DICS. As described above, the third portion 106C and 106C' of the gate dielectric layer 106 may be referred to also herein as 'DICS-doped layer' by the diffused DICS. The difference in thickness between the third portion 106C and the third portion 106C' of the gate dielectric layer 106 may be caused as a portion of the third portion 106C is removed upon removal of the dipole inducing source layer.

FIGS. 12A to 12G illustrate an example of a method for fabricating the semiconductor device 300.

First, a barrier 17 and a first gate electrode 18 may be formed in a gate trench 15 by the method described in FIGS. 4A to 4C.

Subsequently, referring to FIG. 12A, a dipole inducing source layer 51A may be formed. The dipole inducing source layer 51A may be formed over the gate dielectric layer 16 and conformally to the interior walls of the gate trench 15. The dipole inducing source layer 51A may be formed by using an Atomic Layer Deposition (ALD) process or a Chemical Vapor Deposition (CVD) process. The dipole inducing source layer 51A may include DICS. The DICS may include lanthanum atoms. The dipole inducing source layer 51A may include a lanthanum oxide (La_2O_3) or lanthanum oxide monolayer. In accordance with an embodiment, the dipole inducing source layer 51A may include an yttrium oxide (Y_2O_3), a germanium oxide (GeO_2), a lutetium oxide (Lu_2O_3), or a strontium oxide (SrO). The dipole inducing source layer 51A may have a thickness of approximately 20 Å or less. The dipole inducing source layer 51A may have a thickness of approximately 1 to 20 Å.

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Referring to FIG. 12B, a heat treatment 52 may be performed. The heat treatment 52 may include a Rapid Thermal Annealing (RTA). The dipole inducing source layer 51A may be exposed to the heat treatment 52. When the heat treatment 52 is performed, DICS may be diffused from the dipole inducing source layer 51A. The diffused DICS may be locally positioned inside the gate dielectric layer 16. The DICS may be diffused into a portion where the gate dielectric layer 16 contacts with the dipole inducing source layer 51A. Thus, a DICS-diffused portion 51L' may be locally formed in the gate dielectric layer 16. The DICS diffusion portion 51L' may include the diffused DICS. The DICS diffused portion 51L' may include lanthanum atoms. The DICS diffusion portion 51L' may be of a lanthanum-diffused silicon oxide. The DICS diffused portion 51L' may be of a lanthanum silicate.

Referring to FIG. 12C, the dipole inducing source layer 51A may be removed. The dipole inducing source layer 51A may be removed by a wet etching process. By applying the wet etching process, the dipole inducing source layer 51A may be selectively removed without attacking the gate dielectric layer 16. Herein, the dipole inducing source layer 51A that is removed after the heat treatment 52 may be referred to also herein as 'a sacrificial layer including DICS'. In accordance with an embodiment, the wet etching process may be performed by a mixture of HCl/HF.

Referring to FIG. 12D, the second conductive layer 20A may be formed over the DICS diffused portion 51L'. The second conductive layer 20A may fill the gate trench 15. The second conductive layer 20A may include any suitable low-resistance metal material. For example, the second conductive layer 20A may include a titanium nitride. The second conductive layer 20A may be formed by a Chemical Vapor Deposition (CVD) process or an Atomic Layer Deposition (ALD) process.

Referring to FIG. 12E, a second gate electrode 20 may be formed in the gate trench 15. For forming the second gate electrode 20, a recessing process may be performed. The recessing process may include performing dry etching, for example, an etch-back process. The second gate electrode 20 may be formed by an etch-back process of the second conductive layer 20A. In accordance with an embodiment, the recessing process may include first performing a planarization process for exposing the hard mask HM, and then performing an etch-back process following the planarization process. The planarization process may be any suitable planarization process including but not limited to a chemical mechanical polishing. The top surface of the second gate electrode 20 may be recessed lower than the top surface of the active region 14. A portion of the DICS diffused portion 51L' may be exposed by the second gate electrode 20.

Referring to FIG. 12F, a dipole inducing portion 51L may be formed. The dipole inducing portion 51L may contact both sidewalls of the second gate electrode 20. For forming the dipole inducing portion 51L, the exposed portion of the DICS diffused portion 51L' may be selectively removed. For example, the DICS diffused portion 51L' that is not in contact with the second gate electrode 20 may be removed by a wet etching process. In accordance with an embodiment, the wet etching process may be performed by a mixture of HCl/HF. The top surfaces of the dipole inducing portion 51L and the second gate electrode 20 may be positioned at the same level. The top surface of the dipole inducing portion 51L may be recessed lower than the top surface of the active region 14.

The dipole inducing portion 51L may be in the form of a spacer contacting the sidewall of the second gate electrode

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20. The dipole inducing portion 51L may not be positioned between the first gate electrode 18 and the second gate electrode 20.

After the dipole inducing portion 51L is formed, the gate dielectric layer 16 may remain as a first portion 16A and a second portion 16B. The second portion 16B may include the dipole inducing portion 51L, and the dipole inducing portion 51L may include DICS. The dipole inducing portion 51L may correspond to the third portion 106C of FIG. 10B.

As a result, the dipole inducing portion 51L may be formed in the gate dielectric layer 16. After the dipole inducing portion 51L is formed, a portion of the second portion 16B of the gate dielectric layer 16 where the dipole inducing portion 51L is not formed may be exposed.

Referring to FIG. 12G, a capping layer 21 may be formed over the dipole inducing portion 51L and the second gate electrode 20.

After the capping layer 21 is formed, a first source/drain region 22 and a second source/drain region 23 may be formed in the active region 14.

FIGS. 13A to 13E illustrate an example of a method for fabricating the semiconductor device 300'.

Referring to FIGS. 12A and 12B, a process of forming the dipole inducing source layer 51A and a process of performing the heat treatment 52 may be sequentially performed. Accordingly, the DICS diffused portion 51L' may be locally formed in the gate dielectric layer 16.

Subsequently, referring to FIG. 13A, the dipole inducing source layer 51A may be removed. When the dipole inducing source layer 51A is removed, the surface of the DICS diffused portion 51L' may be partially removed. As a result, a thin DICS diffused portion 51L'' may be formed in the gate dielectric layer 16.

Referring to FIG. 13B, a second conductive layer 20A may be formed over the thin DICS diffused portion 51L''. The second conductive layer 20A may fill the gate trench 15. The second conductive layer 20A may include any suitable low-resistance metal material. For example, the second conductive layer 20A may include a titanium nitride. The second conductive layer 20A may be formed by a Chemical Vapor Deposition (CVD) process or an Atomic Layer Deposition (ALD) process.

Referring to FIG. 13C, a second gate electrode 20' may be formed in the gate trench 15. For forming the second gate electrode 20', a recessing process may be performed. The recessing process may include performing dry etching, for example, an etch-back process. The second gate electrode 20' may be formed by an etch-back process of the second conductive layer 20A. In accordance with an embodiment, the recessing process may include first performing a planarization process for exposing the hard mask HM, and then performing an etch-back process following the planarization process. The planarization process may be any suitable planarization process including but not limited to a chemical mechanical polishing. The top surface of the second gate electrode 20' may be recessed lower than the top surface of the active region 14. The width of the second gate electrode 20' may be wider than the width of the second gate electrode of FIG. 12E. A portion of the thin DICS diffused portion 51L'' may be exposed by the second gate electrode 20'.

Referring to FIG. 13D, a dipole inducing portion 51T may be formed. The dipole inducing portion 51T may contact both sidewalls of the second gate electrode 20'. The thin DICS diffused portion 51L'' may be selectively removed to form the dipole inducing portion 51T. For example, the thin DICS diffused portion 51L'' that does not contact the second gate electrode 20' may be removed by a wet etching process.

The top surfaces of the dipole inducing portion **51T** and the second gate electrode **20'** may be positioned at the same level. The top surface of the dipole inducing portion **51T** may be recessed lower than the top surface of the active region **14**.

The dipole inducing portion **51T** may have a form of a spacer. The dipole inducing portion **51T** may not be positioned between and be in direct contact with the first gate electrode **18** and the second gate electrode **20'**.

After the dipole inducing portion **51T** is formed, the gate dielectric layer **16** may remain as a first portion **16A** and a second portion **16B**. The thickness of the second portion **16B** may be thinner than the thickness of the first portion **16A**. After the dipole inducing portion **51T** is formed, a portion of the second portion **16B** of the gate dielectric layer **16** where the dipole inducing portion **51T** is not formed may be exposed.

Referring to FIG. 13E, a capping layer **21** may be formed over the dipole inducing portion **51T** and the second gate electrode **20'**.

After the capping layer **21** is formed, a first source/drain region **22** and a second source/drain region **23** may be formed in the active region **14**.

FIG. 14 is a cross-sectional view illustrating a semiconductor device **400** in accordance with a seventh embodiment of the present invention. Some constituent elements of the semiconductor device **400** may be the same as those of the semiconductor device **300** of FIG. 10A. More specifically, the other constituent elements except for an anti-oxidation barrier **410** may be the same as those of the semiconductor device **300** of FIG. 10A.

Referring to FIG. 14, the semiconductor device **400** may include a buried gate structure **400G**. The buried gate structure **400G** may include a gate dielectric layer **106**, a barrier **107**, a first gate electrode **108**, an anti-oxidation barrier **410**, a dipole inducing portion **309**, a second gate electrode **310**, and a capping layer **111**. The dipole inducing portion **309** may be positioned in the gate dielectric layer **106**.

The anti-oxidation barrier **410** may be positioned between and be in direct contact with the first gate electrode **108** and the second gate electrode **310**. The anti-oxidation barrier **410** may be extended to be positioned between the barrier **107** and the dipole inducing portion **309**. The anti-oxidation barrier **410** may prevent the first gate electrode **108** from being oxidized. For example, it may be possible to prevent the top surface of the first gate electrode **108** from being oxidized during the formation of the dipole inducing portion **309**.

The anti-oxidation barrier **410** may include a conductive material. The anti-oxidation barrier **410** may be a metal-based material for the buried gate structure **400G** to have low resistance. The anti-oxidation barrier **410** may be of a metal nitride. For example, the anti-oxidation barrier **410** may be formed of a titanium nitride. The barrier **107** and the anti-oxidation barrier **410** may be made of the same material. The first gate electrode **108** and the anti-oxidation barrier **410** may be of different materials.

FIG. 15 is a cross-sectional view illustrating a semiconductor device **400'** in accordance with an eighth embodiment of the present invention. Some constituent elements of the semiconductor device **400'** may be the same as those of the semiconductor device **400** of FIG. 14. More specifically, the other constituent elements except for a dipole inducing portion **309'** may be the same as those of the semiconductor device **400** of FIG. 14.

Referring to FIG. 15, the semiconductor device **400'** may include a buried gate structure **400G'**. The buried gate structure **400G'** may include a gate dielectric layer **106**, a barrier **107**, a first gate electrode **108**, an anti-oxidation barrier **410**, a dipole inducing portion **309'**, a second gate electrode **310**, and a capping layer **111**.

The dipole inducing portion **309'** may be positioned between the second gate electrode **310** and the gate dielectric layer **106**. The dipole inducing portion **309'** may not be positioned between and be in direct contact with the first gate electrode **108** and the second gate electrode **310**. The dipole inducing portion **309'** may be spaced from the barrier **107** and the second gate electrode **310** by the anti-oxidation barrier **410**. The first gate electrode **108** and the barrier **107** may be electrically connected to the second gate electrode **310** through the anti-oxidation barrier **410**. Both ends of the anti-oxidation barrier **410** may not contact the bottom portion of the dipole inducing portion **309'**.

The dipole inducing portion **309'** may be locally positioned in the gate dielectric layer **106**. In other words, the dipole inducing portion **309'** may be positioned in the gate dielectric layer **106**.

The thickness of the dipole inducing portion **309'** may be thinner than the thickness of the dipole inducing portion **309** of FIG. 14 ($W2 < W1$). The width of the second gate electrode **310** may be wider than the width of the second gate electrode **310** of FIG. 14 ($W4 > W3$). As a result, the volume of the second gate electrode **310**, which is a low-resistance material, increases, and the gate sheet resistance may be further reduced. In addition, the filling characteristics of the second gate electrode **310** may be further improved.

FIGS. 16A to 16G illustrate an example of a method for fabricating the semiconductor device **400**. More specifically, the other constituent elements except for an anti-oxidation barrier **31** may be similar to those of the method described in FIGS. 12A to 12G.

First, by the method described in FIGS. 7A and 7B, the anti-oxidation barrier **31** and the dummy anti-oxidation layer **31D** may be formed.

Subsequently, referring to FIG. 16A, a dipole inducing source layer **51A** may be formed. The dipole inducing source layer **51A** may be conformally formed. The dipole inducing source layer **51A** may be formed by using a Chemical Vapor Deposition (CVD) process or an Atomic Layer Deposition (ALD) process. The dipole inducing source layer **51A** may include DICS. The DICS may include lanthanum atoms. The dipole inducing source layer **51A** may include a lanthanum oxide (La_2O_3). In accordance with an embodiment, the dipole inducing source layer **51A** may include an yttrium oxide (Y_2O_3), a germanium oxide (GeO_2), a lutetium oxide (Lu_2O_3), or a strontium oxide (SrO).

Referring to FIG. 16B, a heat treatment **52** may be performed. The heat treatment **52** may include a Rapid Thermal Annealing (RTA). The dipole inducing source layer **51A** may be exposed to the heat treatment **52**. When the heat treatment **52** is performed, DICS may be diffused from the dipole inducing source layer **51A**. The diffused DICS may be locally positioned in the gate dielectric layer **16**. The DICS may be diffused into a portion of the gate dielectric layer **16** contacting the dipole inducing source layer **51A**. Thus, DICS diffused portion **51L'** may be locally formed in the gate dielectric layer **16**. The DICS diffused portion **51L'** may include DICS. The DICS diffused portion **51L'** may include lanthanum atoms. The DICS diffused portion **51L'** may be of a lanthanum-diffused silicon oxide. The DICS diffused portion **51L'** may be of a lanthanum silicate.

Meanwhile, the DICS may not be diffused into the gate dielectric layer **16** in contact with the dummy anti-oxidation layer **31D**.

Referring to FIG. **16C**, the dipole inducing source layer **51A** may be removed. The dipole inducing source layer **51A** may be removed by a wet etching process. By applying the wet etching process, the dipole inducing source layer **51A** may be selectively removed without attacking the gate dielectric layer **16**. In accordance with an embodiment, the wet etching process may be performed by a mixture of HCl/HF.

Referring to FIG. **16D**, the second conductive layer **20A** may be formed over the diffused inducing chemical species diffused portion **51L'**. The second conductive layer **20A** may fill the gate trench **15**. The second conductive layer **20A** may include any suitable low-resistance metal material. For example, the second conductive layer **20A** may include a titanium nitride. The second conductive layer **20A** may be formed by a Chemical Vapor Deposition (CVD) process or an Atomic Layer Deposition (ALD) process.

Referring to FIG. **16E**, the second gate electrode **20** may be formed in the gate trench **15**. For forming the second gate electrode **20**, a recessing process may be performed. The recessing process may include performing dry etching, for example, an etch-back process. The second gate electrode **20** may be formed by an etch-back process of the second conductive layer **20A**. In accordance with an embodiment, the recessing process may include first performing a planarization process for exposing the hard mask **HM**, and then performing an etch-back process following the planarization process. The planarization process may be any suitable planarization process including but not limited to a chemical mechanical polishing. The top surface of the second gate electrode **20** may be recessed lower than the top surface of the active region **14**.

Referring to FIG. **16F**, a dipole inducing portion **51L** may be formed. The dipole inducing portion **51L** may contact both sidewalls of the second gate electrode **20**. For forming the dipole inducing portion **51L**, the DICS diffused portion **51L'** may be selectively removed. For example, the DICS diffused portion **51L'** that is not in contact with the second gate electrode **20** may be removed by wet etching. The top surfaces of the dipole inducing portion **51L** and the second gate electrode **20** may be positioned at the same level. The top surface of the dipole inducing portion **51L** may be recessed lower than the top surface of the active region **14**.

The dipole inducing portion **51L** may have a form of a spacer. The dipole inducing portion **51L** may not be positioned between and be in direct contact with the first gate electrode **18** and the second gate electrode **20**.

After the dipole inducing portion **51L** is formed, the gate dielectric layer **16** may remain as a first portion **16A** and a second portion **16B** (see FIG. **12F**). The thickness of the second portion **16B** may be thinner than the thickness of the first portion **16A**. After formation of the dipole inducing portion **51L**, a portion of the second portion **16B** of the gate dielectric layer **16** may be exposed.

Referring to FIG. **16G**, a capping layer **21** may be formed over the dipole inducing portion **51L** and the second gate electrode **20**. After formation of the capping layer **21**, a first source/drain region **22** and a second source/drain region **23** may be formed in the active region **14**.

FIG. **17** is a cross-sectional view illustrating a semiconductor device **500**, in accordance with a ninth embodiment of the present invention. Some constituent elements of the semiconductor device **500** may be the same as those of the semiconductor device **300** of FIG. **10A**. More specifically,

the other constituent elements except for a doped interface layer **510** may be the same as those of the semiconductor device **300** of FIG. **10A**.

Referring to FIG. **17**, the semiconductor device **500** may include a buried gate structure **500G**. The buried gate structure **500G** may include a gate dielectric layer **106**, a barrier **107**, a first gate electrode **108**, a dipole inducing portion **309**, a second gate electrode **310**, and a capping layer **111**. The buried gate structure **500G** may further include a doped interface layer **510** between the first gate electrode **108** and the second gate electrode **310**.

The doped interface layer **510** may include a first doped interface layer **1071** and a second doped interface layer **1081**. The first doped interface layer **1071** may be positioned over the barrier **107**. The second doped interface layer **1081** may be positioned over the first gate electrode **108**. The first doped interface layer **1071** may be positioned between the barrier **107** and the second gate electrode **310**. The second doped interface layer **1081** may be positioned between and be in direct contact with the first gate electrode **108** and the second gate electrode **310**. The first doped interface layer **1071** and the second doped interface layer **1081** may be of different materials.

The doped interface layer **510** may include DICS. The DICS may include lanthanum atoms. The doped interface layer **510** may be of a lanthanum atom-doped material. The first doped interface layer **1071** and the second doped interface layer **1081** may be of a material doped with lanthanum atoms. For example, the first doped interface layer **1071** may include a titanium nitride doped with lanthanum atoms. The second doped interface layer **1081** may include tungsten doped with lanthanum atoms.

The dipole inducing portion **309** may include DICS. The dipole inducing portion **309** and the doped interface layer **510** may include the same DICS. The dipole inducing portion **309** and the doped interface layer **510** may include lanthanum atoms. The doped interface layer **510** may be of a conductive material. The dipole inducing portion **309** may be of a lanthanum atom-doped silicon oxide.

FIG. **18** is a cross-sectional view illustrating a semiconductor device **500'** in accordance with a 10th embodiment of the present invention. Some constituent elements of the semiconductor device **500'** may be the same as those of the semiconductor device **500** of FIG. **17**. The constituent elements except for a second gate electrode **310** and a dipole inducing portion **309'** may be the same as those of the semiconductor device **500** of FIG. **17**.

Referring to FIG. **18**, the semiconductor device **500'** may include a buried gate structure **500G'**. The buried gate structure **500G'** may include a gate dielectric layer **106**, a barrier **107**, a first gate electrode **108**, a dipole inducing portion **309'**, a second gate electrode **310**, and a capping layer **111**. The buried gate structure **500G'** may further include a doped interface layer **510** between the first gate electrode **108** and the second gate electrode **310**.

The thickness of the dipole inducing portion **309'** may be thinner than the thickness of the dipole inducing portion **309** of FIG. **17** ($W2 < W1$). The width of the second gate electrode **310** may be wider than the width of the second gate electrode **310** of FIG. **17** ($W4 > W3$). As a result, the volume of the second gate electrode **310**, which is a low-resistance material, increases, and the gate sheet resistance may be further reduced. In addition, the filling characteristics of the second gate electrode **310** may be further improved.

The doped interface layer **510** and the dipole inducing portion **309'** may not contact each other.

FIGS. 19A to 19F illustrate an example of a method for fabricating the semiconductor device shown in FIG. 17.

First, the barrier 17 and the first gate electrode 18 may be formed in the gate trench 15 by the method described in FIGS. 4A to 4C.

Subsequently, Referring to FIG. 19A, a dipole inducing source layer 51A may be formed. The dipole inducing source layer 51A may be conformally formed. The dipole inducing source layer 51A may be formed by using a Chemical Vapor Deposition (CVD) process or an Atomic Layer Deposition (ALD) process. The dipole inducing source layer 51A may include a dipole inducing chemical species (hereinafter "DICS". The DICS may include lanthanum atoms. The dipole inducing source layer 51A may include a lanthanum oxide (La_2O_3). In accordance with an embodiment, the dipole inducing source layer 51A may include an yttrium oxide (Y_2O_3), a germanium oxide (GeO_2), a lutetium oxide (Lu_2O_3), or a strontium oxide (SrO).

Subsequently, a heat treatment 52' may be performed. The heat treatment 52' may include a Rapid Thermal Annealing (RTA) of the dipole inducing source layer 51A. When the heat treatment 52' is performed, DICS may be diffused from the dipole inducing source layer 51A. The diffused DICS may be locally positioned in the gate dielectric layer 16. The DICS may be diffused into a portion that the gate dielectric layer 16 contacts the dipole inducing source layer 51A. Thus, a DICS diffused portion 51L' may be locally formed in the gate dielectric layer 16. The DICS diffused portion 51L' may include DICS. The DICS diffused portion 51L' may include lanthanum atoms. The DICS diffused portion 51L' may be of a lanthanum-doped silicon oxide. The DICS diffused portion 51L' may be of a lanthanum silicate.

During the heat treatment 52', the DICS may be diffused into the barrier 17 and the first gate electrode 18. The DICS may be diffused from the dipole inducing source layer 51A into the barrier 17 and the first gate electrode 18. As a result, a first doped interface layer 171 may be formed in the top surface of the barrier 17, and a second doped interface layer 181 may be formed in the top surface of the first gate electrode 18. Since the barrier 17 is of a titanium nitride, the first doped interface layer 171 may be of a lanthanum atom-diffused titanium nitride. Since the first gate electrode 18 is of tungsten, the second doped interface layer 181 may be of lanthanum atoms-diffused tungsten.

Referring to FIG. 19B, the dipole inducing source layer 51A may be removed. The dipole inducing source layer 51A may be removed by a wet etching process. By applying the wet etching process, the dipole inducing source layer 51A may be selectively removed without attacking the gate dielectric layer 16. In accordance with an embodiment, the wet etching process may be performed by a mixture of HCl/HF.

Referring to FIG. 19C, a second conductive layer 20A may be formed over the DICS diffused portion 51L' and the first and second doped interface layers 171 and 181. The second conductive layer 20A may fill the gate trench 15. The second conductive layer 20A may include any suitable low-resistance metal material. For example, the second conductive layer 20A may include a titanium nitride. The second conductive layer 20A may be formed by a Chemical Vapor Deposition (CVD) process or an Atomic Layer Deposition (ALD) process.

Referring to FIG. 19D, a second gate electrode 20 may be formed in the gate trench 15. For forming the second gate electrode 20, a recessing process may be performed. The recessing process may include a dry etching process, for

example, an etch-back process. The second gate electrode 20 is formed by an etch-back process of the second conductive layer 20A. In accordance with an embodiment, the recessing process may include first performing a planarization process for exposing the hard mask HM, and then performing an etch-back process following the planarization process. The planarization process may be any suitable planarization process including but not limited to a chemical mechanical polishing. The top surface of the second gate electrode 20 may be recessed lower than the top surface of the active region 14.

Referring to FIG. 19E, a dipole inducing portion 51L may be formed. The dipole inducing portion 51L may contact both sidewalls of the second gate electrode 20. For forming the dipole inducing portion 51L, the DICS diffused portion 51L' may be selectively removed. For example, the DICS diffused portion 51L' that is not in contact with the second gate electrode 20 may be removed by a wet etching process. The top surfaces of the dipole inducing portion 51L and the second gate electrode 20 may be positioned at the same level. The top surface of the dipole inducing portion 51L may be recessed lower than the top surface of the active region 14.

The dipole inducing portion 51L may have a form of a spacer. The dipole inducing portion 51L may not be positioned between and be in direct contact with the first gate electrode 18 and the second gate electrode 20.

After formation of the dipole inducing portion 51L, the gate dielectric layer 16 may remain as a first portion 16A and a second portion 16B (see FIG. 12F). The thickness of the second portion 16B may be thinner than the thickness of the first portion 16A. After formation of the dipole inducing portion 51L, a portion of the second portion 16B of the gate dielectric layer 16 may be exposed.

Referring to FIG. 19F, a capping layer 21 may be formed over the dipole inducing portion 51L and the second gate electrode 20.

After formation of the capping layer 21, a first source/drain region 22 and a second source/drain region 23 may be formed in the active region 14.

FIGS. 20A and 20B illustrate an example of a method for fabricating the semiconductor device shown in FIG. 18.

First, a barrier 17 and a first gate electrode 18 may be formed in the gate trench 15 by the method described in FIGS. 4A to 4C.

Subsequently, referring to FIG. 19A, a dipole inducing source layer 51A may be formed. The dipole inducing source layer 51A may be conformally formed. The dipole inducing source layer 51A may be formed by using a Chemical Vapor Deposition (CVD) process or an Atomic Layer Deposition (ALD) process. The dipole inducing source layer 51A may include DICS. The DICS may include lanthanum atoms. The dipole inducing source layer 51A may include a lanthanum oxide (La_2O_3). In accordance with an embodiment, the dipole inducing source layer 51A may include an yttrium oxide (Y_2O_3), a germanium oxide (GeO_2), a lutetium oxide (Lu_2O_3), or a strontium oxide (SrO).

Subsequently, a heat treatment 52' may be performed. The heat treatment 52' may include a Rapid Thermal Annealing (RTA). The dipole inducing source layer 51A may be exposed to the heat treatment 52'. When the heat treatment 52' is performed, DICS may be diffused from the dipole inducing source layer 51A. The diffused DICS may be locally positioned in the gate dielectric layer 16. The DICS may be diffused into a portion of the gate dielectric layer 16 that contacts the dipole inducing source layer 51A. There-

fore, DICS diffused portion 51L' may be locally formed in the gate dielectric layer 16. The DICS diffused portion 51L' may include the DICS. The DICS diffused portion 51L' may include lanthanum atoms. The DICS diffused portion 51L' may be of a lanthanum-doped silicon oxide. The DICS diffused portion 51L' may be of a lanthanum silicate.

The DICS may be diffused from the dipole inducing source layer 51A into the barrier 17 and the first gate electrode 18 during the heat treatment 52'. A first doped interface layer 171 may be formed in the top surface of the barrier 17, and a second doped interface layer 181 may be formed in the top surface of the first gate electrode 18. Since the barrier 17 is a titanium nitride, the first doped interface layer 171 may be a lanthanum atom-diffused titanium nitride. Since the first gate electrode 18 is tungsten, the second doped interface layer 181 may be lanthanum atom-diffused tungsten.

Subsequently, referring to FIG. 20A, the dipole inducing source layer 51A may be removed. The dipole inducing source layer 51A may be removed by a wet etching process. By applying the wet etch process, the dipole inducing source layer 51A may be selectively removed without attacking the gate dielectric layer 16.

When the dipole inducing source layer 51A is removed, the surface of the DICS diffused portion 51L' may be partially removed. As a result, a thinned DICS diffused portion 51T may be formed.

The first doped interface layer 171 and the second doped interface layer 181 may remain without loss.

Subsequently, a dipole inducing portion, a second gate electrode, a capping layer, first and second source/drain regions may be sequentially formed by the method described in FIGS. 19C to 19F. Referring to FIG. 20B, the dipole inducing portion 51L may be positioned in the gate dielectric layer 16. A second gate electrode 20' may be formed over the dipole inducing portion 51L. A capping layer 21 may be formed over the second gate electrode 20'. A second doped interface layer 181 may be formed between the second gate electrode 20' and the first gate electrode 18. A first doped interface layer 171 may be formed between the second gate electrode 20' and the barrier 17.

After the capping layer 21 is formed, a first source/drain region 22 and a second source/drain region 23 may be formed in the active region 14.

FIG. 21 is a cross-sectional view illustrating a semiconductor device 600 in accordance with an 11th embodiment of the present invention. Some constituent elements of the semiconductor device 600 may be the same as those of the semiconductor device 400 of FIG. 14. More specifically, the other constituent elements except for a doped anti-oxidation barrier 410I may be the same as those of the semiconductor device 400 of FIG. 14.

Referring to FIG. 21, the semiconductor device 600 may include a buried gate structure 600G. The buried gate structure 600G may include a gate dielectric layer 106, a barrier 107, a first gate electrode 108, an anti-oxidation barrier 410, a dipole inducing portion 309, a second gate electrode 310, and a capping layer 111. The buried gate structure 600G may further include a doped anti-oxidation barrier 410I between the first gate electrode 108 and the second gate electrode 310.

The doped anti-oxidation barrier 410I may be positioned between the second gate electrode 310 and the first gate electrode 108. The doped anti-oxidation barrier 410I may be positioned between the barrier 107 and the second gate electrode 310.

The doped anti-oxidation barrier 410I may be positioned in the anti-oxidation barrier 410.

The doped anti-oxidation barrier 410I may include DICS. The anti-oxidation barrier 410 may not include DICS. The DICS may include lanthanum atoms. The doped anti-oxidation barrier 410I may be of a lanthanum-doped material.

The dipole inducing portion 309 may include DICS. The dipole inducing portion 309 and the doped anti-oxidation barrier 410I may include the same DICS. The dipole inducing portion 309 and the doped anti-oxidation barrier 410I may include lanthanum atoms individually. The dipole inducing portion 309 may include a dielectric material, and the doped anti-oxidation barrier 410I may include a conductive material. The dipole inducing portion 309 may be of a lanthanum atom-doped silicon oxide. The doped anti-oxidation barrier 410I may include a titanium nitride doped with lanthanum atoms. The anti-oxidation barrier 410 may include an undoped titanium nitride.

FIG. 22 is a cross-sectional view illustrating a semiconductor device 600' in accordance with a 12th embodiment of the present invention. Some constituent elements of the semiconductor device 600' may be the same as those of the semiconductor device 600 of FIG. 21. More specifically, the other constituent elements except for a dipole inducing portion 309' may be the same as those of the semiconductor device 600 of FIG. 21.

Referring to FIG. 22, the semiconductor device 600' may include a buried gate structure 600G'. The buried gate structure 600G' may include a gate dielectric layer 106, a barrier 107, a first gate electrode 108, a dipole inducing portion 309', a second gate electrode 310, and a capping layer 111. The buried gate structure 600G' may further include an anti-oxidation barrier 410 and a doped anti-oxidation barrier 410I between the first gate electrode 108 and the second gate electrode 310.

The thickness of the dipole inducing portion 309' may be thinner than the thickness of the dipole inducing portion 309 of FIG. 21 ($W2 < W1$). The width of the second gate electrode 310 may be wider than the width of the second gate electrode 310 of FIG. 21 ($W4 > W3$). As a result, the volume of the second gate electrode 310, which is a low-resistance material, increases, and the gate sheet resistance may be further reduced. In addition, the filling characteristics of the second gate electrode 310 may be further improved.

The doped anti-oxidation barrier 410I and the dipole inducing portion 309' may not contact each other.

FIG. 23 is a cross-sectional view illustrating a semiconductor device 700 in accordance with a 13th embodiment of the present invention. Some constituent elements of the semiconductor device 700 may be the same as those of the semiconductor device 300 of FIG. 10. More specifically, the other constituent elements except for a first gate electrode 708 may be the same as those of the semiconductor device 300 of FIG. 10.

Referring to FIG. 23, the semiconductor device 700 may include a buried gate structure 700G. The buried gate structure 700G may include a gate dielectric layer 106, a first gate electrode 708, a dipole inducing portion 309, a second gate electrode 310, and a capping layer 111.

The dipole inducing portion 309 may be positioned in the gate dielectric layer 106. The dipole inducing portion 309 may be in direct contact with the second gate electrode 310. The dipole inducing portion 309 may not be positioned between and be in direct contact with the first gate electrode 708 and the second gate electrode 310.

The first gate electrode 708 may be formed of a material that does not attack the gate dielectric layer 106. For

example, the first gate electrode **708** may be formed of a material that does not contain any impurity, e.g., fluorine, i.e., a fluorine-free material. Thus, the barrier between the first gate electrode **708** and the gate dielectric layer **106** may be omitted. The first gate electrode **708** may include a titanium nitride. Since the first gate electrode **708** is of a fluorine-free material, the first gate electrode **708** may be referred to also herein as 'a barrier-less gate electrode'. The first gate electrode **708** in FIG. **23** is of a titanium nitride. The titanium nitride may not attack the gate dielectric layer **106**. Since the barrier is omitted, the filling characteristic of the first gate electrode **708** may be improved.

The first gate electrode **708** and the second gate electrode **310** may be made of the same material. For example, the first gate electrode **70** and the second gate electrode **310** may each be formed of a titanium nitride. Accordingly, the first gate electrode **708** and the second gate electrode **310** may be 'a TiN-only gate electrode'.

The top surface of the dipole inducing portion **309** may be positioned at a lower level than the top surface of the substrate **101**.

The dipole inducing portion **309** may be locally positioned in the gate dielectric layer **106**. In other words, the dipole inducing portion **309** may be positioned in the gate dielectric layer **106**. The dipole inducing portion **309** may overlap with the first and second source/drain regions **112** and **113** in the horizontal direction (see I-I').

Since the dipole inducing portion **309** is positioned in the gate dielectric layer **106**, the filling characteristics of the second gate electrode **310** may be improved. The suppression of the gate induced drain leakage (GIDL) may be improved by a dipole inducing portion **309** containing DICS.

FIG. **24** is a cross-sectional view illustrating a semiconductor device **700'** in accordance with a 14th embodiment of the present invention. Some constituent elements may be the same as those of the semiconductor device **700** of FIG. **23**. More specifically, the other constituent elements except for a dipole inducing portion **309'** may be the same as those of the semiconductor device **700** of FIG. **23**.

Referring to FIG. **24**, the semiconductor device **700'** may include a buried gate structure **700G'**. The buried gate structure **700G'** may include a gate dielectric layer **106**, a first gate electrode **708**, a dipole inducing portion **309'**, a second gate electrode **310**, and a capping layer **111**.

The thickness of the dipole inducing portion **309'** may be thinner than the thickness of the dipole inducing portion **309** of FIG. **23** ($W2 < W1$). The width of the second gate electrode **310** may be wider than the width of the second gate electrode **310** of FIG. **23** ($W4 > W3$). As a result, the volume of the second gate electrode **310**, which is a low-resistance material, increases, and the gate sheet resistance may be further reduced. In addition, the filling characteristics of the second gate electrode **310** may be further improved.

FIG. **25** is a cross-sectional view illustrating a semiconductor device **800** in accordance with a 15th embodiment of the present invention. Some constituent elements of the semiconductor device **800** may be the same as those of the semiconductor device **700** of FIG. **23**. More specifically, the other constituent elements except for a doped interface layer **410I** may be the same as those of the semiconductor device **700** of FIG. **23**.

Referring to FIG. **25**, the semiconductor device **800** may include a buried gate structure **800G**. The buried gate structure **800G** may include a gate dielectric layer **106**, a first gate electrode **708**, a dipole inducing portion **309**, a second gate electrode **310**, and a capping layer **111**. The buried gate

structure **800G** may further include a doped interface layer **410I** between the first gate electrode **708** and the second gate electrode **310**.

The doped interface layer **410I** may be positioned between and be in direct contact with the first gate electrode **708** and the second gate electrode **310**.

The doped interface layer **410I** may comprise DICS. The DICS may include lanthanum atoms. The doped interface layer **410I** may be a lanthanum atom-doped material. For example, the doped interface layer **410I** may include a titanium nitride doped with lanthanum atoms.

The dipole inducing portion **309** may include DICS. The dipole inducing portion **309** and the doped interface layer **410I** may include the same DICS. The dipole inducing portion **309** and the doped interface layer **410I** may include lanthanum atoms, individually. The dipole inducing portion **309** may be of a dielectric material, and the doped interface layer **410I** may be of a conductive material. The dipole inducing portion **309** may be a lanthanum atom-doped silicon oxide.

FIG. **26** is a cross-sectional view illustrating a semiconductor device **800'** in accordance with a 16th embodiment of the present invention. Some constituent elements of the semiconductor device **800'** may be the same as those of the semiconductor device **800** of FIG. **25**. More specifically, the other constituent elements except for a dipole inducing portion **309'** may be the same as those of the semiconductor device **800** of FIG. **25**.

Referring to FIG. **26**, the semiconductor device **800'** may include a buried gate structure **800G'**. The buried gate structure **800G'** may include a gate dielectric layer **106**, a first gate electrode **708**, a dipole inducing portion **309'**, a second gate electrode **310**, and a capping layer **111**. The buried gate structure **800G'** may further include a doped interface layer **410I** between the first gate electrode **708** and the second gate electrode **310**.

The thickness of the dipole inducing portion **309'** may be thinner than the thickness of the dipole inducing portion **309** of FIG. **25** ($W2 < W1$). The width of the second gate electrode **310** may be wider than the width of the second gate electrode **310** of FIG. **25** ($W4 > W3$). As a result, the volume of the second gate electrode **310**, which is a low-resistance material, increases, and the gate sheet resistance may be further reduced. In addition, the filling characteristics of the second gate electrode **310** may be further improved.

FIG. **27** is a cross-sectional view illustrating a semiconductor device **900** in accordance with a 17th embodiment of the present invention. Some constituent elements of the semiconductor device **900** may be the same as those of the semiconductor device **800** of FIG. **25**. More specifically, the other constituent elements except for a second gate electrode **710** may be the same as those of the semiconductor device **800** of FIG. **25**.

Referring to FIG. **27**, the semiconductor device **900** may include a buried gate structure **900G**. The buried gate structure **900G** may include a gate dielectric layer **106**, a first gate electrode **708**, a dipole inducing portion **309**, a second gate electrode **710**, and a capping layer **111**. The buried gate structure **900G** may further include a doped interface layer **410I** between the first gate electrode **708** and the second gate electrode **710**.

The first gate electrode **708** and the second gate electrode **710** may be of different materials. For example, the second gate electrode **710** may be formed of polysilicon. The second gate electrode **710** may be formed of polysilicon having a low work function. The second gate electrode **710** may be formed of polysilicon doped with an N-type impu-

rity (hereinafter, referred to as an N-type polysilicon). When the N-type polysilicon is applied as the second gate electrode **710**, the agglomeration issue may be improved. The second gate electrode **710** may include polysilicon (N⁺ Poly Si) doped with a high-concentration N-type impurity.

The first gate electrode **708** may be formed of a titanium nitride, and the second gate electrode **710** may be formed of an N-type polysilicon.

Referring to FIG. 27, the buried gate structure **900G** may include a dual gate electrode formed of a first gate electrode **708** and a second gate electrode **710**. A doped interface layer **410I** may be positioned between and be in direct contact with the first gate electrode **708** and the second gate electrode **710**. A dipole inducing portion **309** may be positioned between the second gate electrode **710** and the gate dielectric layer **106**. A dipole inducing portion **309** may be positioned in the gate dielectric layer **106**. The dipole inducing portion **309** may overlap with the first and second source/drain regions **112** and **113** in the horizontal direction. The doped interface layer **410I** and the dipole inducing portion **309** may commonly include DICS. The DICS may include lanthanum atoms.

FIG. 28 is a cross-sectional view illustrating a semiconductor device **900'** in accordance with an 18th embodiment of the present invention. Some constituent elements of the semiconductor device **900'** may be the same as those of the semiconductor device **900** of FIG. 27. More specifically, the other constituent elements except for a dipole inducing portion **309'** may be the same as those of the semiconductor device **900** of FIG. 27.

Referring to FIG. 28, the semiconductor device **900'** may include a buried gate structure **900G'**. The buried gate structure **900G'** may include a gate dielectric layer **106**, a first gate electrode **708**, a dipole inducing portion **309'**, a second gate electrode **710**, and a capping layer **111**. The buried gate structure **900G'** may further include a doped interface layer **410I** between the first gate electrode **708** and the second gate electrode **710**.

The thickness of the dipole inducing portion **309'** may be thinner than the thickness of the dipole inducing portion **309** of FIG. 27 ($W2 < W1$). The width of the second gate electrode **310** may be wider than the width of the second gate electrode **310** of FIG. 27 ($W4 > W3$). As a result, the volume of the second gate electrode **310**, which is a low-resistance material, increases, and the gate sheet resistance may be further reduced. In addition, the filling characteristics of the second gate electrode **310** may be further improved.

The first gate electrode **708** and the second gate electrode **710** may be of different materials. For example, the second gate electrode **710** may be formed of polysilicon. The second gate electrode **710** may be formed of polysilicon having a low work function. The second gate electrode **710** may be formed of polysilicon doped with an N-type impurity (hereinafter, referred to as an N-type polysilicon). When the N-type polysilicon is applied as the second gate electrode **710**, the agglutination issue may be improved.

The first gate electrode **708** may be formed of a titanium nitride, and the second gate electrode **710** may be formed of an N-type polysilicon.

Referring to FIG. 28, the buried gate structure **900G'** may include a dual gate electrode formed of a first gate electrode **708** and a second gate electrode **710**. A doped interface layer **410I** may be positioned between and be in direct contact with the first gate electrode **708** and the second gate electrode **710**. A dipole inducing portion **309'** may be positioned between the second gate electrode **710** and the gate dielectric layer **106**. A dipole inducing portion **309'** may be

positioned in the gate dielectric layer **106**. The dipole inducing portion **309'** may overlap with the first and second source/drain regions **112** and **113** in the horizontal direction. The doped interface layer **410I** and the dipole inducing portion **309'** may include the same DICS. The DICS may include lanthanum atoms.

FIG. 29 is a cross-sectional view illustrating a semiconductor device **910** in accordance with a 19th embodiment of the present invention. Some constituent elements of the semiconductor device **910** may be the same as those of the semiconductor device **900** of FIG. 27. More specifically, the other constituent elements except for an anti-oxidation barrier **410** and a doped anti-oxidation barrier **410I** may be the same as those of the semiconductor device **900** of FIG. 27.

Referring to FIG. 29, the semiconductor device **910** may include a buried gate structure **910G**. The buried gate structure **910G** may include a gate dielectric layer **106**, a first gate electrode **708**, a dipole inducing portion **309**, a second gate electrode **710**, and a capping layer **111**. The buried gate structure **910G** may further include an anti-oxidation barrier **410** and a doped anti-oxidation barrier **410I** between the first gate electrode **708** and the second gate electrode **710**.

The doped anti-oxidation barrier **410I** may be positioned between the second gate electrode **310** and the first gate electrode **108**. The doped anti-oxidation barrier **410I** may be positioned between the barrier **107** and the second gate electrode **310**.

The doped anti-oxidation barrier **410I** may be positioned in the anti-oxidation barrier **410**.

The doped anti-oxidation barrier **410I** may include DICS. The anti-oxidation barrier **410** may not include DICS. The DICS may include lanthanum atoms. The doped anti-oxidation barrier **410I** may be a lanthanum atom-doped material.

The first gate electrode **708** and the second gate electrode **710** may be of different materials. For example, the second gate electrode **710** may be formed of polysilicon. The second gate electrode **710** may be formed of polysilicon having a low work function. The second gate electrode **710** may be formed of polysilicon (N⁺ poly Si) doped with a high-concentration N-type impurity.

The first gate electrode **708** may be formed of a titanium nitride, and the second gate electrode **710** may be formed of an N-type polysilicon.

According to FIG. 29, the buried gate structure **900G** may include a dual gate electrode formed of a first gate electrode **708** and a second gate electrode **710**. An anti-oxidation barrier **410** and a doped anti-oxidation barrier **410I** may be positioned between and be in direct contact with the first gate electrode **708** and the second gate electrode **710**. A dipole inducing portion **309** may be positioned between the second gate electrode **710** and the gate dielectric layer **106**. A dipole inducing portion **309** may be positioned in the gate dielectric layer **106**. The dipole inducing portion **309** may overlap with the first and second source/drain regions **112** and **113** in the horizontal direction. The doped anti-oxidation barrier **410I** and the dipole inducing portion **309** may include the same DICS. The DICS may include lanthanum atoms.

FIG. 30 is a cross-sectional view illustrating a semiconductor device in accordance with a 20th embodiment of the present invention. Some constituent elements of the semiconductor device **920** may be the same as the semiconductor device **910** of FIG. 29. More specifically, the other constituent elements except for a dipole inducing portion **309'** may be the same as the semiconductor device **910** of FIG. 29.

Referring to FIG. 30, the semiconductor device 920 may include a buried gate structure 920G. The buried gate structure 920G may include a gate dielectric layer 106, a first gate electrode 708, a dipole inducing portion 309', a second gate electrode 710, and a capping layer 111. The buried gate structure 920G may further include an anti-oxidation barrier 410 and a doped anti-oxidation barrier 410I between the first gate electrode 708 and the second gate electrode 710.

The doped anti-oxidation barrier 410I may be positioned between the second gate electrode 310 and the first gate electrode 108. The doped anti-oxidation barrier 410I may be positioned between the barrier 107 and the second gate electrode 310.

The doped anti-oxidation barrier 410I may be positioned in the anti-oxidation barrier 410.

The doped anti-oxidation barrier 410I may include DICS. The anti-oxidation barrier 410 may not include DICS. The DICS may include lanthanum atoms. The doped anti-oxidation barrier 410I may be a lanthanum-doped material.

The thickness of the dipole inducing portion 309' may be thinner than the thickness of the dipole inducing portion 309 of FIG. 29 ($W2 < W1$). The width of the second gate electrode 710 may be wider than the width of the second gate electrode 710 of FIG. 27 ($W4 > W3$). As a result, the volume of the second gate electrode 710, which is a low-resistance material, increases, and the gate sheet resistance may be further reduced. In addition, the filling characteristics of the second gate electrode 710 may be further improved.

The first gate electrode 708 and the second gate electrode 710 may be of different materials. For example, the second gate electrode 710 may be formed of polysilicon. The second gate electrode 710 may be formed of polysilicon having a low work function. The second gate electrode 710 may be formed of polysilicon (N^+ Poly Si) doped with a high-concentration N-type impurity.

The first gate electrode 708 may be formed of a titanium nitride, and the second gate electrode 710 may be formed of an N-type polysilicon.

Referring to FIG. 30, the buried gate structure 900G' may include a dual gate electrode formed of a first gate electrode 708 and a second gate electrode 710. An anti-oxidation barrier 410 and a doped anti-oxidation barrier 410I may be positioned between and be in direct contact with the first gate electrode 708 and the second gate electrode 710. A dipole inducing portion 309' may be positioned between the second gate electrode 710 and the gate dielectric layer 106. A dipole inducing portion 309' may be positioned in the gate dielectric layer 106. The dipole inducing portion 309' may overlap with the first and second source/drain regions 112 and 113 in the horizontal direction. The doped interface layer 410I and the dipole inducing portion 309' may include the same DICS. The DICS may include lanthanum atoms.

FIGS. 31A to 31G illustrate an example of a method for fabricating the semiconductor device 600. More specifically, the other constituent elements except for a doped anti-oxidation barrier 311 may be similar to the method described in FIGS. 16A to 16G.

First, an anti-oxidation barrier 31 and a dummy anti-oxidation layer 31D may be formed by the method described in FIGS. 7A and 7B.

Subsequently, referring to FIG. 31A, a dipole inducing source layer 51A may be formed over the gate dielectric layer 16, the anti-oxidation barrier 31, and the dummy anti-oxidation layer 31D. The dipole inducing source layer 51A may be conformally formed. The dipole inducing source layer 51A may be formed by using a Chemical Vapor Deposition (CVD) process or an Atomic Layer Deposition

(ALD) process. The dipole inducing source layer 51A may include DICS. The DICS may include lanthanum atoms. The dipole inducing source layer 51A may include a lanthanum oxide. In accordance with an embodiment, the dipole inducing source layer 51A may include an yttrium oxide, a germanium oxide, a lutetium oxide, or a strontium oxide.

Referring to FIG. 31B, a heat treatment 52 may be performed. The heat treatment 52 may include a Rapid Thermal Annealing (RTA). When the heat treatment 52 is performed, DICS may be diffused from the dipole inducing source layer 51A. The diffused DICS may be locally positioned in the gate dielectric layer 16. The DICS may be diffused into a portion of the gate dielectric layer 16 that contacts the dipole inducing source layer 51A. As a result, DICS diffused portion 51L' may be locally formed in the gate dielectric layer 16. The DICS diffused portion 51L' may include DICS. The DICS diffused portion 51L' may include lanthanum atoms. The DICS diffused portion 51L' may be a lanthanum-doped silicon oxide. The DICS diffused portion 51L' may be a lanthanum silicate.

During the heat treatment 52, the DICS may be diffused into the anti-oxidation barrier 31. As a result, a doped anti-oxidation barrier 311 may be formed in the anti-oxidation barrier 31. The doped anti-oxidation barrier 311 may include a lanthanum atom-diffused titanium nitride.

Meanwhile, the DICS may not be diffused into the gate dielectric layer 16 that contacts the dummy anti-oxidation layer 31D.

Referring to FIG. 31C, the dipole inducing source layer 51A may be removed. The dipole inducing source layer 51A may be removed by a wet etching process. By applying the wet etching process, the dipole inducing source layer 51A may be selectively removed without attacking the gate dielectric layer 16. In accordance with an embodiment, the wet etching process may be performed by a mixture of HCl/HF.

In accordance with an embodiment of the present invention, when the dipole inducing source layer 51A is removed, the surface of the DICS diffused portion 51L' may be partially removed. As a result, a dipole inducing portion 309' of the semiconductor device 600' described in FIG. 22 may be formed.

Referring to FIG. 31D, the second conductive layer 20A may be formed over the inducing chemical species diffused portion 51L'. The second conductive layer 20A may fill the gate trench 15. The second conductive layer 20A may include any suitable low-resistance metal material. For example, the second conductive layer 20A may include a titanium nitride. The second conductive layer 20A may be formed by a Chemical Vapor Deposition (CVD) process or an Atomic Layer Deposition (ALD) process.

Referring to FIG. 31E, a second gate electrode 20 may be formed in the gate trench 15. For forming the second gate electrode 20, a recessing process may be performed. The recessing process may include performing dry etching, for example, an etch-back process. The second gate electrode 20 may be formed by an etch-back process of the second conductive layer 20A. In accordance with an embodiment, the recessing process may include first performing a planarization process for exposing the hard mask HM, and then performing an etch-back process following the planarization process. The planarization process may be any suitable planarization process including but not limited to a chemical mechanical polishing. The top surface of the second gate electrode 20 may be recessed lower than the top surface of the active region 14. A portion of the DICS diffused portion 51L' may be exposed by the second gate electrode 20.

Referring to FIG. 31F, a dipole inducing portion 51L may be formed. The dipole inducing portion 51L may contact both sidewalls of the second gate electrode 20. For forming the dipole inducing portion 51L, the DICS diffused portion 51L' may be selectively removed. For example, the DICS diffused portion 51L' that is not in contact with the second gate electrode 20 may be removed by a wet etching process. The top surfaces of the dipole inducing portion 51L and the second gate electrode 20 may be positioned at the same level. The top surface of the dipole inducing portion 51L may be recessed lower than the top surface of the active region 14.

The dipole inducing portion 51L may have a form of a spacer. The dipole inducing portion 51L may not be positioned between and be in direct contact with the first gate electrode 18 and the second gate electrode 20.

After the dipole inducing portion 51L is formed, the gate dielectric layer 16 may remain as a first portion 16A and a second portion 16B (see FIG. 12F).

Referring to FIG. 31G, a capping layer 21 may be formed over the dipole inducing portion 51L and the second gate electrode 20. After the capping layer 21 is formed, a first source/drain region 22 and a second source/drain region 23 may be formed in the active region 14.

In accordance with an embodiment, for forming the semiconductor device 700 shown in FIG. 23, the barrier may be omitted. For example, the barrier 17 may be omitted in FIG. 31A, and then the first gate electrode 18 may be formed. Herein, the first gate electrode 18 may include a titanium nitride. The subsequent processes will be referred to FIGS. 31A to 31G.

FIG. 32 is a cross-sectional view illustrating a memory cell.

Referring to FIG. 32, a memory cell 1000M may be shown. The memory cell 1000M may include a cell transistor, a bit line BL, and a capacitor CAP. The cell transistor may be the semiconductor device 100 of FIG. 2A. Therefore, the cell transistor may include a buried gate structure 100G, a channel region CH, a first source/drain region 112, and a second source/drain region 113. The first source/drain region 112 may be electrically connected to the bit line BL. The second source/drain region 113 may be electrically connected to the capacitor CAP.

In the memory cell 1000M, the buried gate structure 100G may be referred to also herein as a buried word line structure BWL. The buried word line structure BWL may be positioned in the gate trench 105. The buried word line structure BWL may include a gate dielectric layer 106, a barrier 107, a first gate electrode 108, a dipole inducing layer 109, a second gate electrode 110, and a capping layer 111. The dipole inducing layer 109 may include a lanthanum oxide or a lanthanum oxide monolayer. The dipole inducing layer 109 may include an interface portion 1091, a first side portion 109S1, and a second side portion 109S2. The interface portion 1091 may be formed between the first gate electrode 108 and the second gate electrode 110. The first and second side portions 109S1 and 109S2 may be formed between the second gate electrode 110 and the gate dielectric layer 106. The first side portion 109S1 may be positioned between the first source/drain region 112 and the second gate electrode 110. The second side portion 109S2 may be positioned between the second source/drain region 113 and the second gate electrode 110.

The buried gate structure 100G may be replaced with one among the buried gate structures of the above-described embodiments.

The capacitor CAP may include a storage node, a dielectric layer, and a plate node. The storage node may be in the form of a cylinder or a pillar. A capacitor dielectric layer may be formed on the surface of the storage node. The dielectric layer may include at least one selected from the group including a zirconium oxide, an aluminum oxide, and a hafnium oxide. For example, the dielectric layer may have a ZAZ structure in which a first zirconium oxide, an aluminum oxide, and a second zirconium oxide are stacked. A plate node may be formed over the dielectric layer. The storage node and the plate node may include a metal-containing material.

The memory cell 1000M may be part of a DRAM. When the memory cell 1000M is applied to a DRAM, the refresh characteristic of the DRAM can be improved. In addition, it is possible to improve the retention time by preventing off-leakage.

In accordance with the embodiments of the present invention, the gate-induced drain leakage (GIDL) may be decreased by forming a dipole inducing layer or a dipole inducing portion between a buried gate electrode and a source/drain region.

Also, in accordance with the embodiments of the present invention, the sheet resistance of a buried gate electrode may be reduced.

While the present invention has been described with respect to the specific embodiments, it will be apparent to those skilled in the art that various changes and modifications may be made without departing from the spirit and scope of the invention as defined in the following claims.

What is claimed is:

1. A semiconductor device, comprising:

- a substrate;
- a first source/drain region and a second source/drain region spaced apart from each other by a trench in the substrate; and
- a gate structure in the trench, wherein the gate structure includes:
 - a gate dielectric layer formed on a bottom and sidewalls of the trench;
 - a first gate electrode positioned in a bottom portion of the trench over the gate dielectric layer;
 - a second gate electrode positioned over the first gate electrode;
 - a capping layer disposed over the second gate electrode; and
 - a dipole inducing layer formed between the first gate electrode and the second gate electrode and between sidewalls of the second gate electrode and the gate dielectric layer, wherein the dipole inducing layer extends between the capping layer and the gate dielectric layer, and wherein a top surface of the dipole inducing layer is at a same level as a top surface of the first and second source/drain regions.

2. The semiconductor device of claim 1, wherein the dipole inducing layer is in direct contact with the gate dielectric layer and the sidewalls of the second gate electrode.

3. The semiconductor device of claim 1, wherein the dipole inducing layer is thin enough to electrically connect the first gate electrode and the second gate electrode.

4. The semiconductor device of claim 1, wherein the gate dielectric layer and the dipole inducing layer have different oxygen atom areal density.

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5. The semiconductor device of claim 1, wherein the dipole inducing layer includes a material having a smaller oxygen atom areal density than the gate dielectric layer.

6. The semiconductor device of claim 1, wherein the dipole inducing layer includes a material that reduces a work function value of the second gate electrode.

7. The semiconductor device of claim 1, wherein the dipole inducing layer includes lanthanum.

8. The semiconductor device of claim 1, wherein the dipole inducing layer includes a lanthanum oxide or a lanthanum oxide monolayer.

9. The semiconductor device of claim 1, wherein the gate dielectric layer includes a silicon oxide, and the dipole inducing layer includes a lanthanum oxide or a lanthanum oxide monolayer.

10. The semiconductor device of claim 1, wherein the gate dielectric layer includes a first metal oxide, and the dipole inducing layer includes a second metal oxide, where the second metal oxide has a smaller oxygen atom areal density than the first metal oxide.

11. The semiconductor device of claim 1, wherein the first gate electrode and the second gate electrode include a metal nitride.

12. The semiconductor device of claim 1, wherein the first gate electrode includes a metal, and the second gate electrode includes a metal nitride, and further includes a metal nitride barrier formed between the first gate electrode and the gate dielectric layer.

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13. The semiconductor device of claim 1, wherein the first gate electrode includes a metal-based material, and the second gate electrode includes an N-type doped polysilicon.

14. The semiconductor device of claim 1, wherein a portion of the dipole inducing layer horizontally overlaps with the first and second source/drain regions.

15. The semiconductor device of claim 1, further comprising:

a fin region formed below the trench, wherein the gate dielectric layer and the first gate electrode cover a top surface and sidewalls of the fin region.

16. The semiconductor device of claim 1, further comprising:

an anti-oxidation barrier formed between the first gate electrode and the dipole inducing layer.

17. The semiconductor device of claim 16, wherein the anti-oxidation barrier includes a metal nitride.

18. The semiconductor device of claim 1, wherein the first gate electrode includes tungsten or a titanium nitride, and the second gate electrode includes a titanium nitride or an N-type doped polysilicon, and the dipole inducing layer includes a lanthanum oxide.

19. The semiconductor device of claim 1, wherein the dipole inducing layer is in direct contact with an upper portion of the first gate electrode and a bottom portion of the second gate electrode.

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