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**(54) SEMICONDUCTOR DEVICE AND ITS  
MANUFACTURING METHOD**

## Publication Classification

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H01L 31/062

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## ABSTRACT

A semiconductor device includes: an  $n^+$  type drain region; an  $n$  type drift region that connects with the  $n^+$  type drain region; a  $p$  type body region; a  $n^+$  type source region that connects with the  $p$  type body region; and a gate electrode that is provided, with being covered by a gate insulation film, in a gate trench that penetrates the  $p$  type body region. The semiconductor further includes: a  $p$  type silicon region that adjoins the  $n$  type drift region; and an  $n$  type silicon region provided in a region almost including a carrier passage that connects the  $n$  type drift region and the  $p$  type body region. Here, the  $p$  type silicon region and the  $p$  type body region directly connect with each other.

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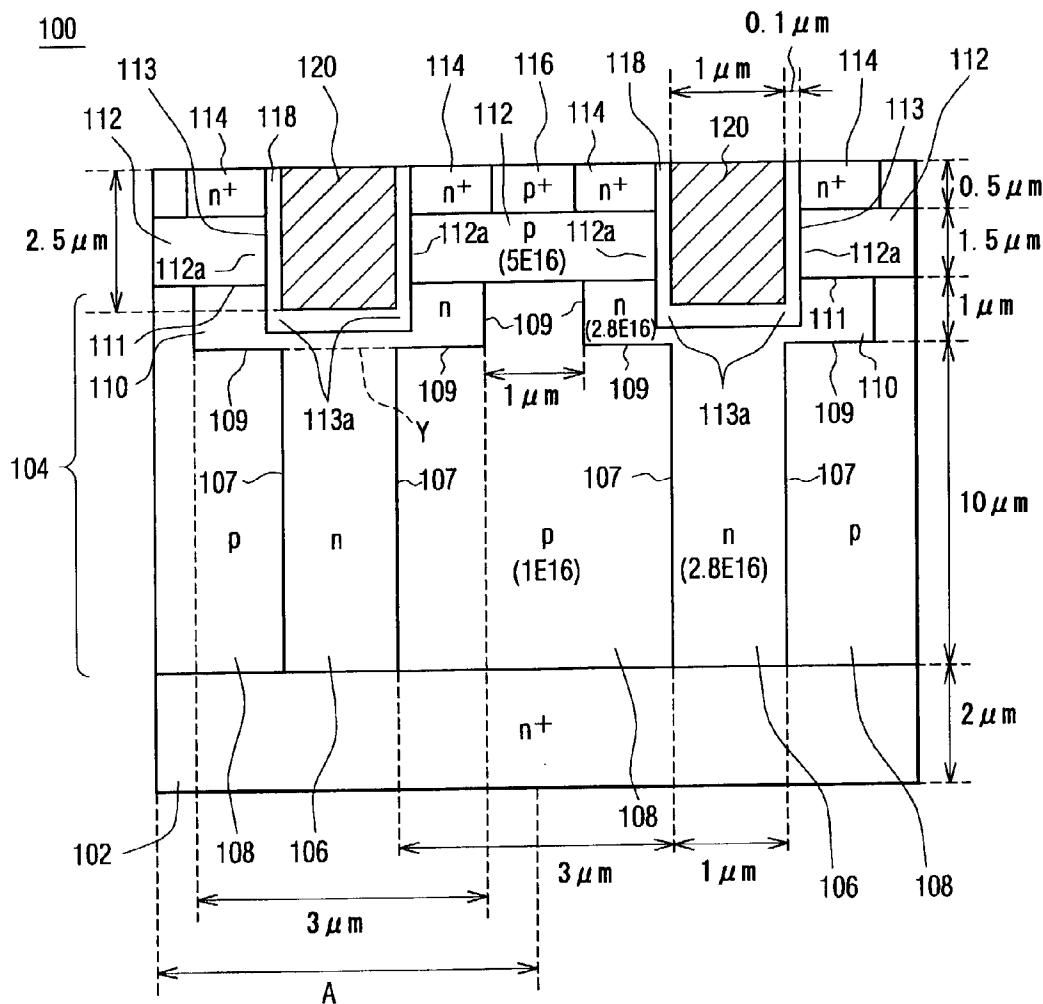
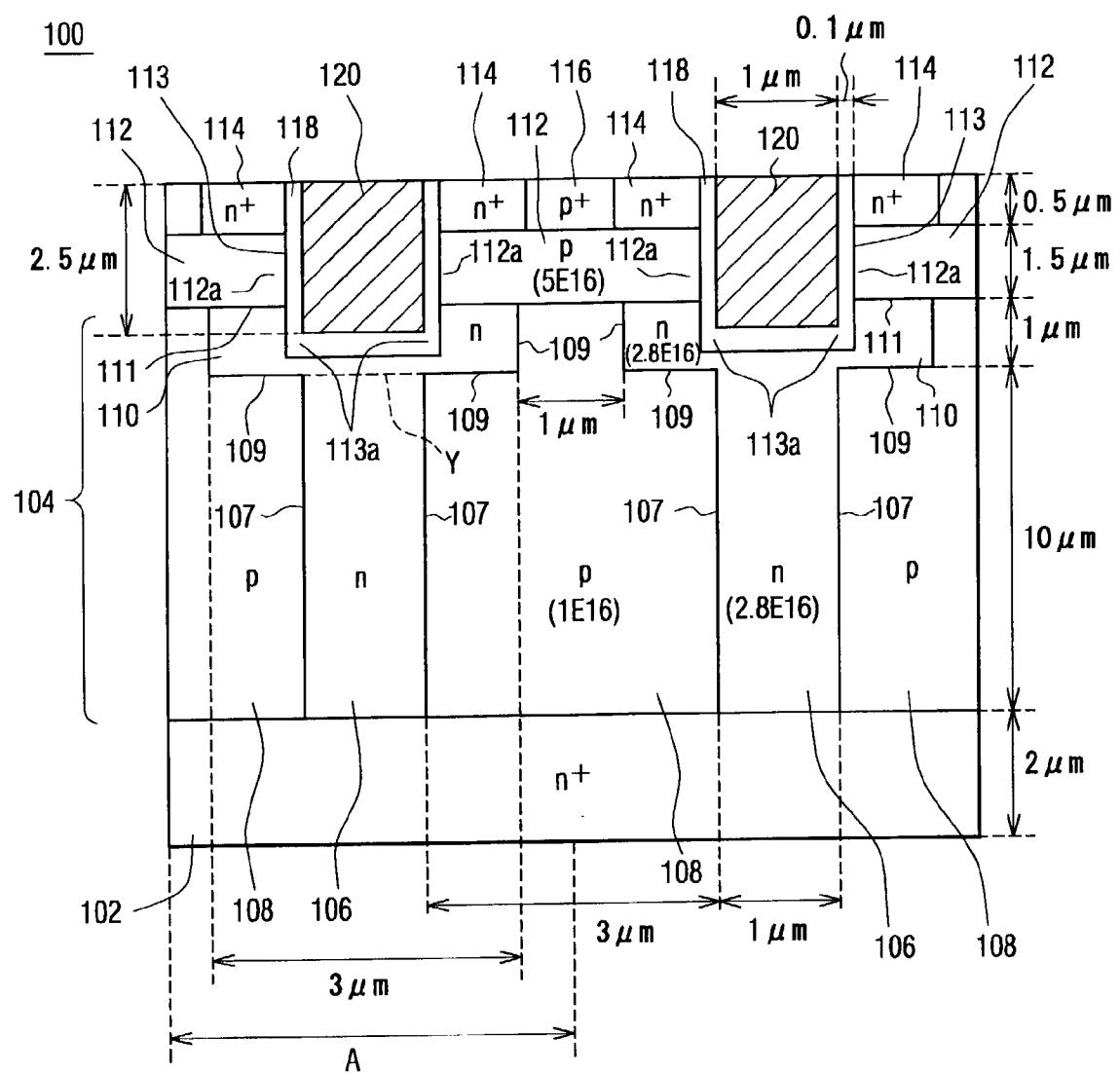
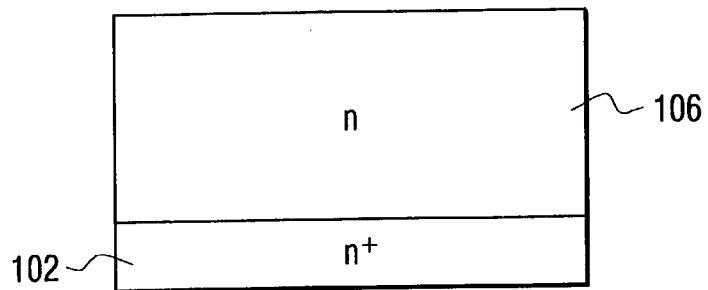


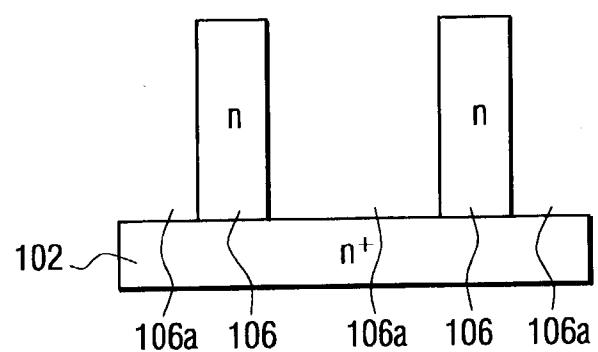
FIG. 1



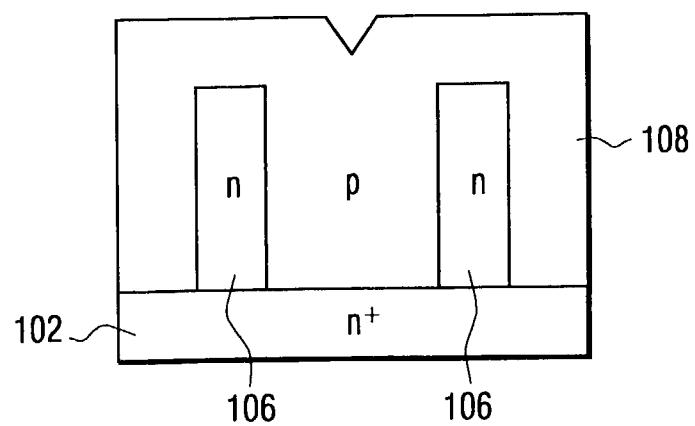
**FIG. 2**



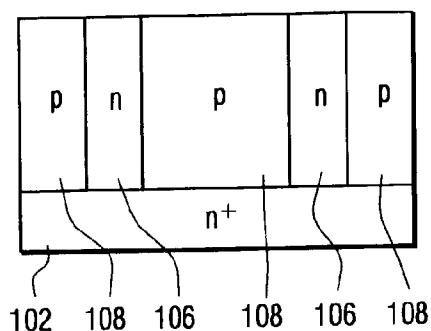
**FIG. 3**



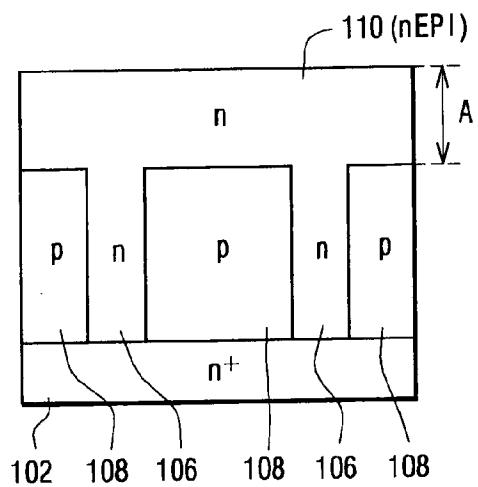
**FIG. 4**



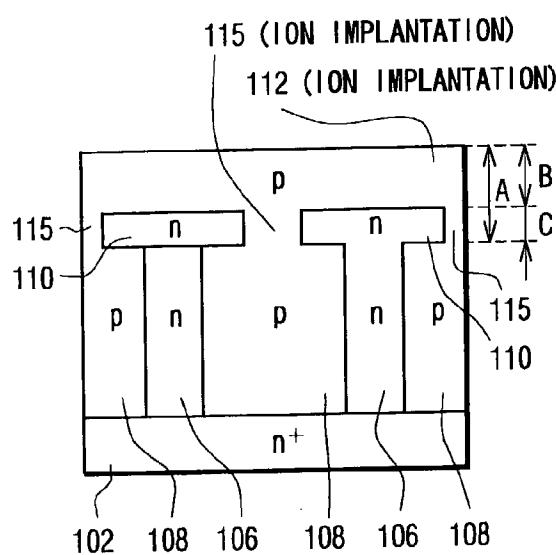
**FIG. 5**



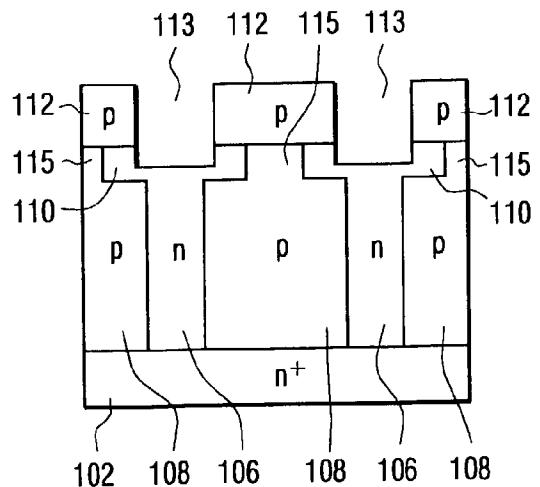
**FIG. 6**



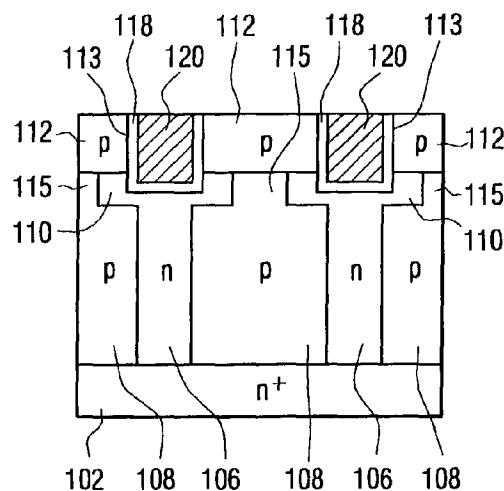
**FIG. 7**



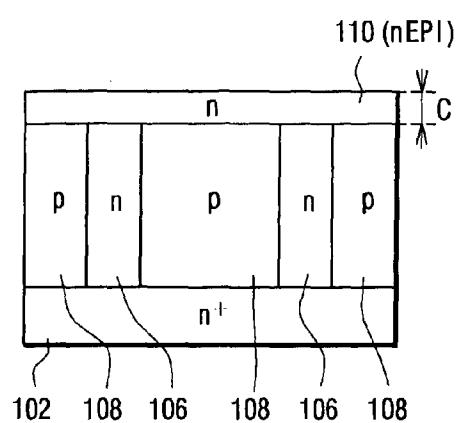
**FIG. 8**



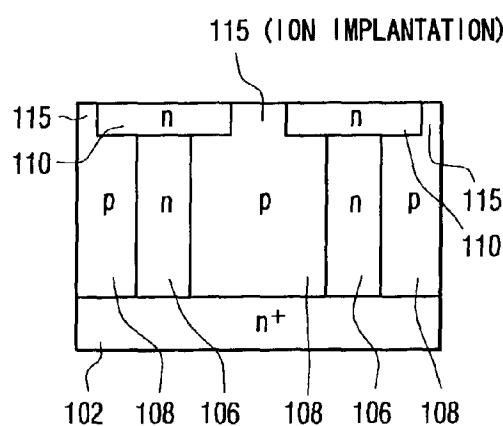
**FIG. 9**



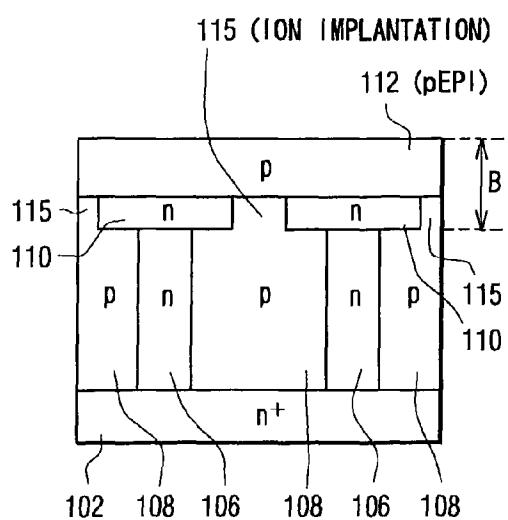
**FIG. 10**



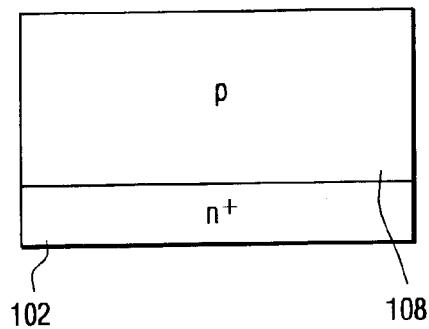
**FIG. 11**



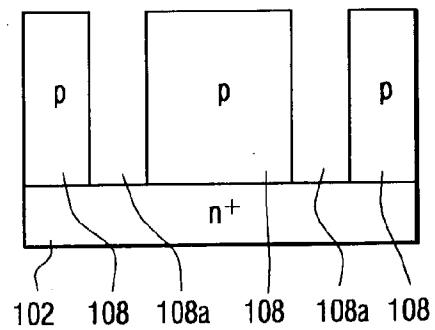
**FIG. 12**



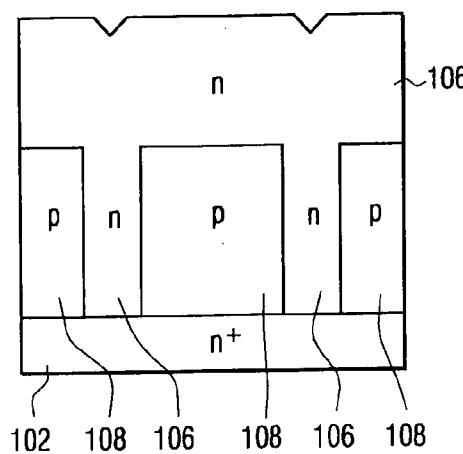
**FIG. 13**



**FIG. 14**



**FIG. 15**



**FIG. 16**

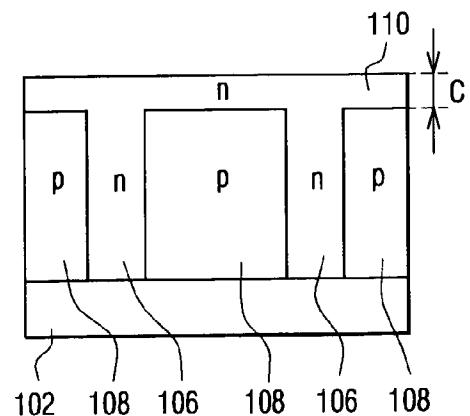


FIG. 17

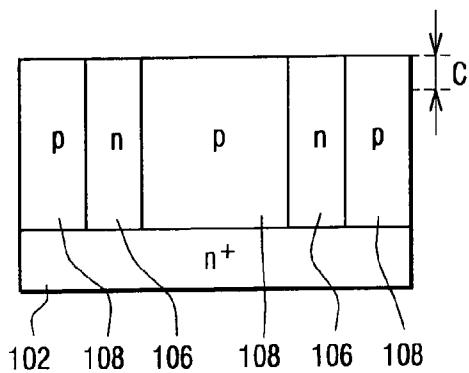


FIG. 18

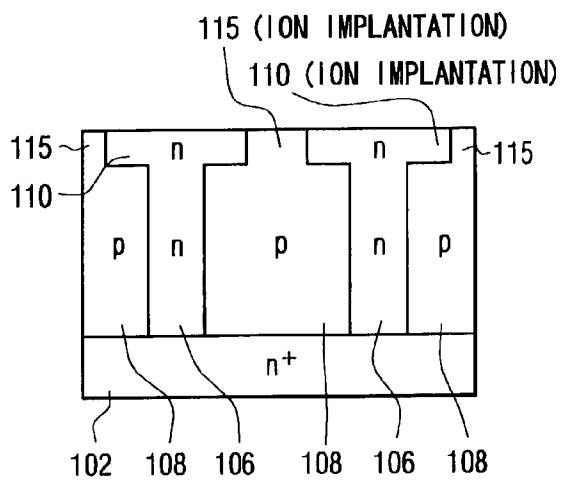


FIG. 19

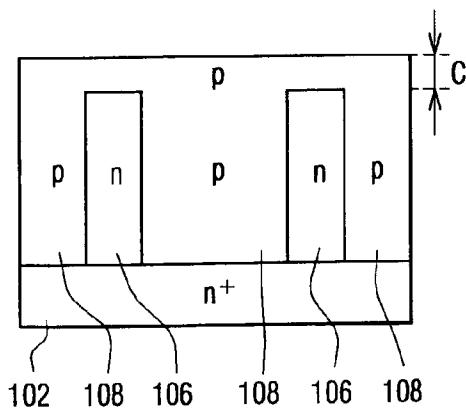


FIG. 20

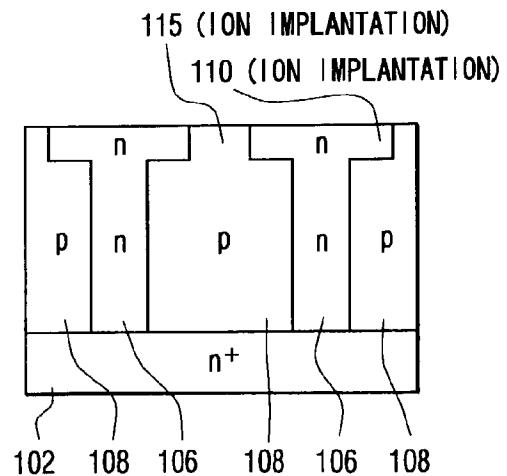


FIG. 21

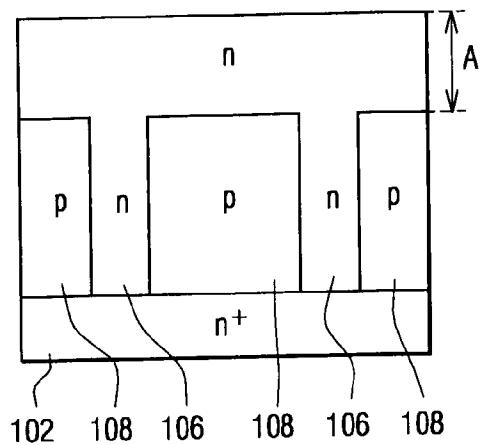


FIG. 22

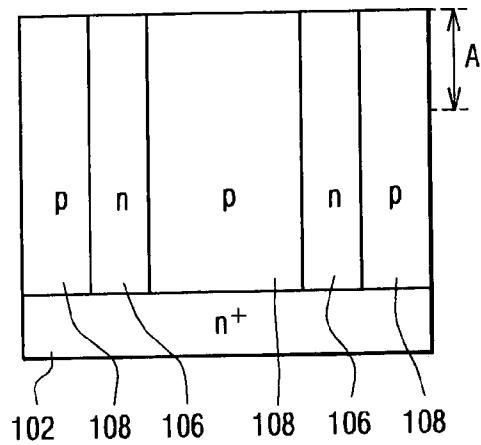


FIG. 23

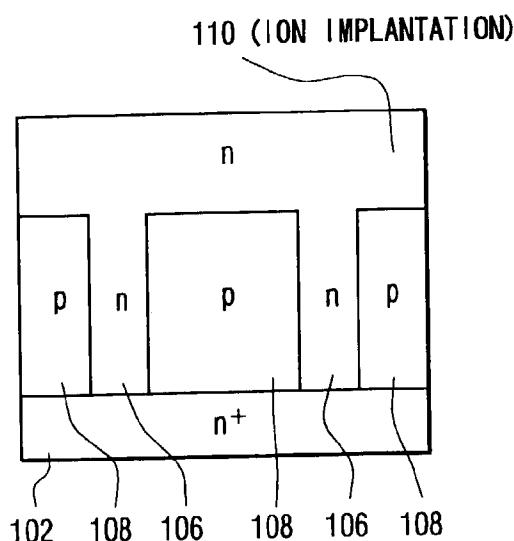


FIG. 24

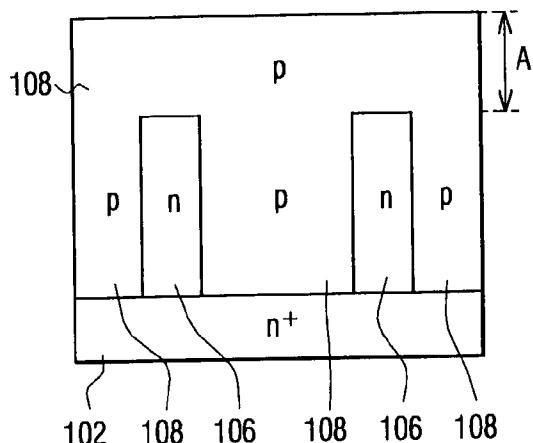


FIG. 25

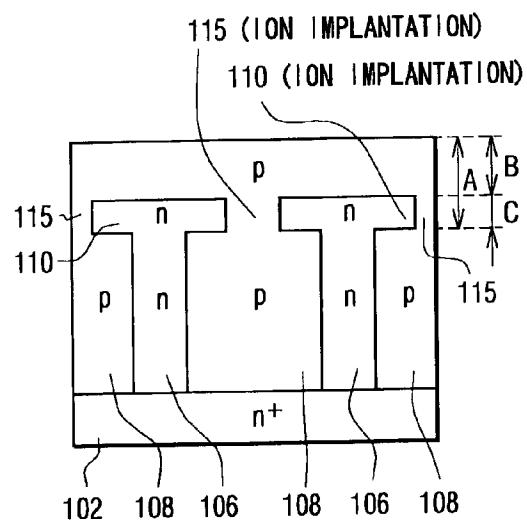


FIG. 26

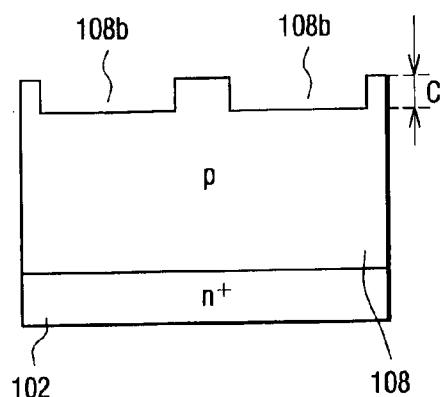


FIG. 27

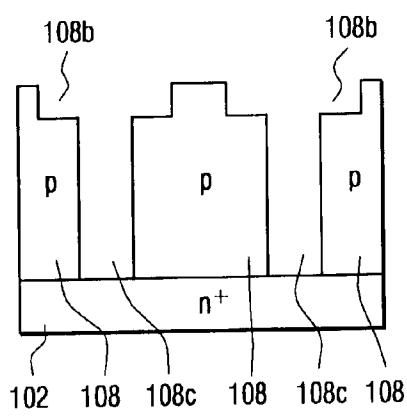


FIG. 28

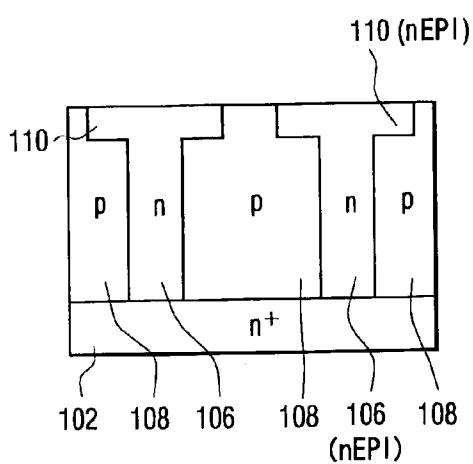


FIG. 29

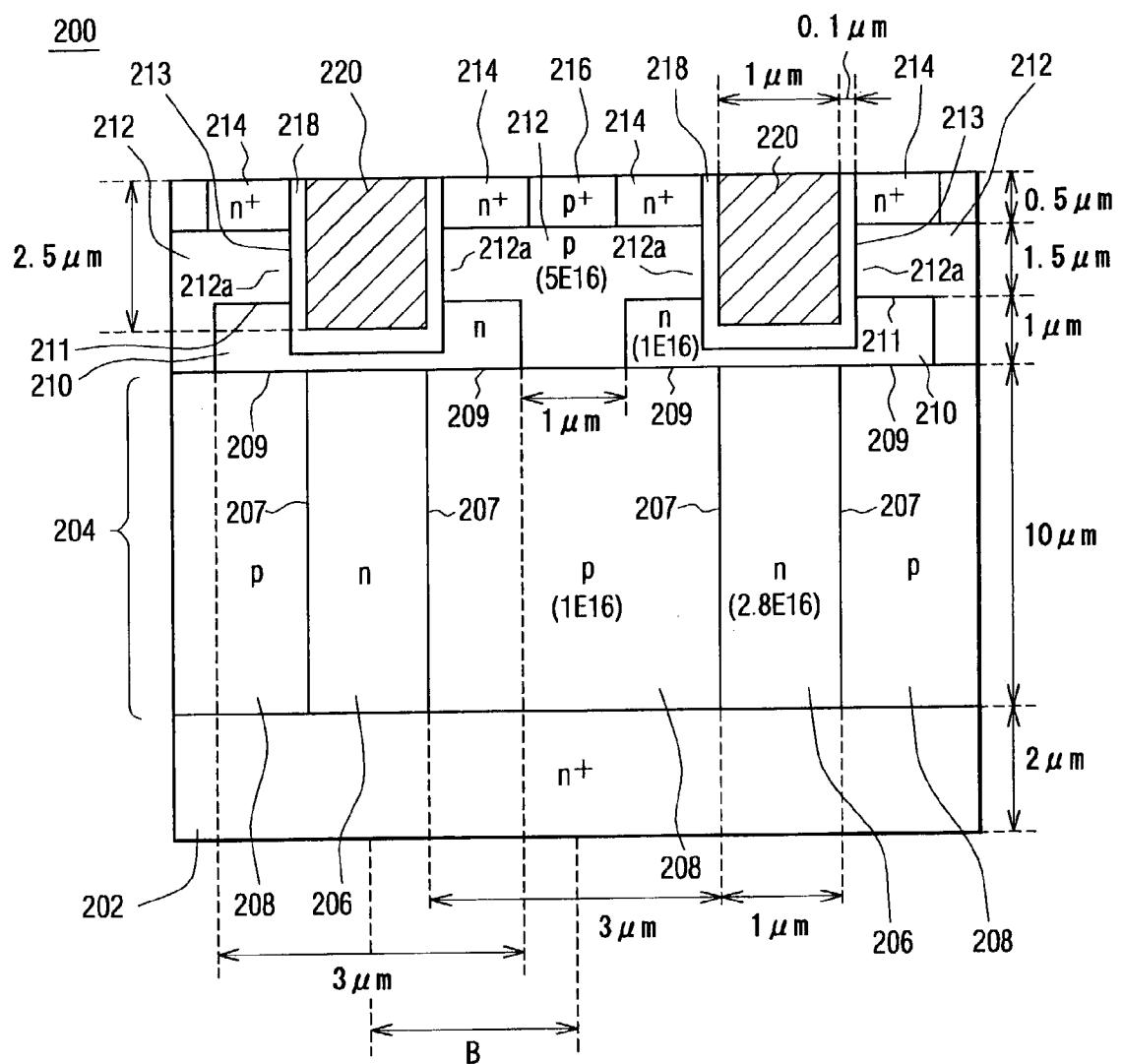


FIG. 30

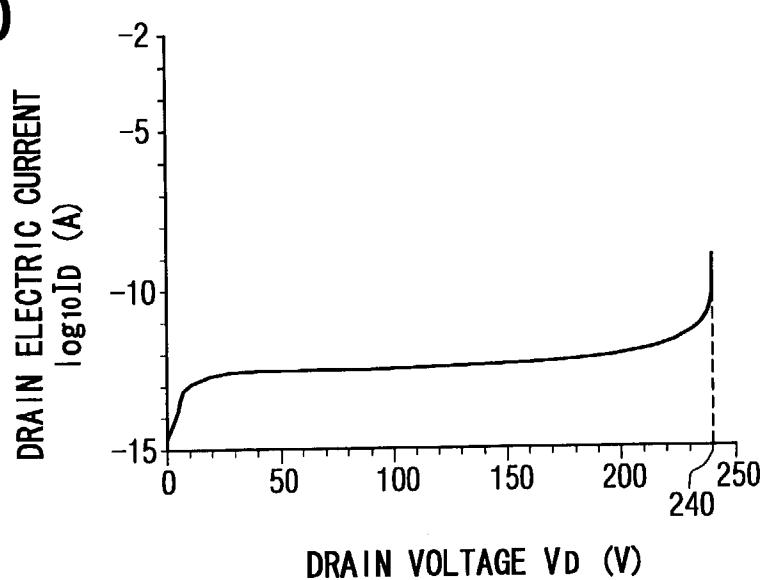
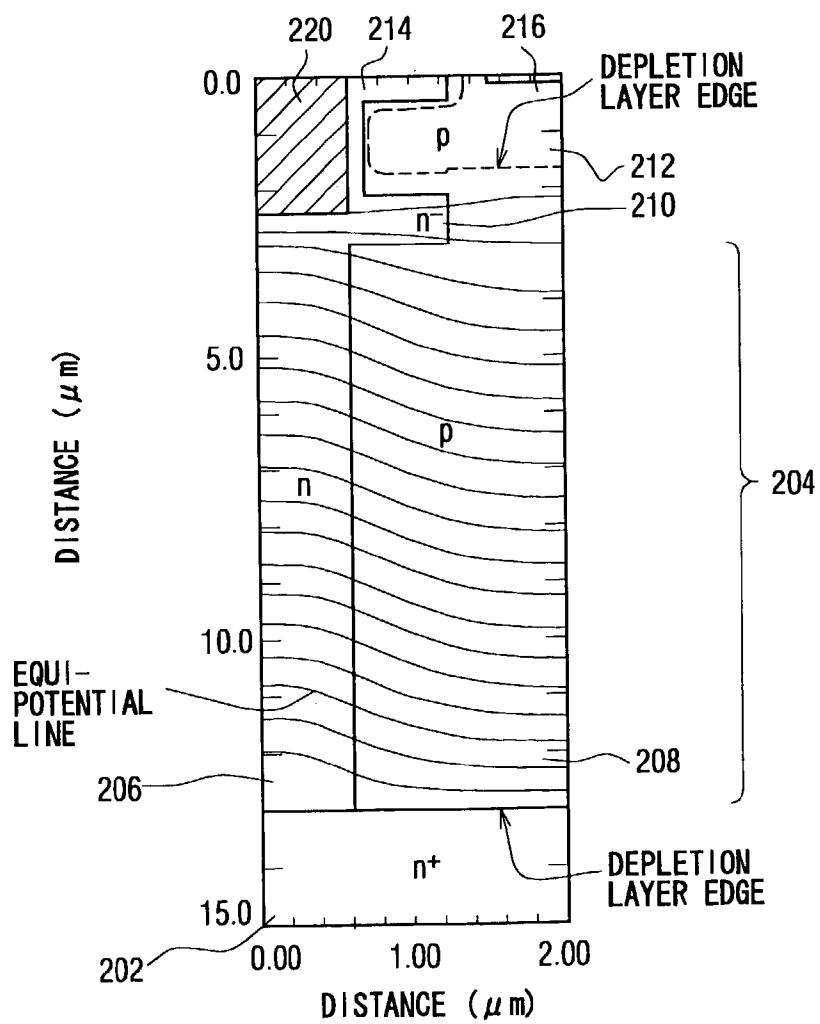
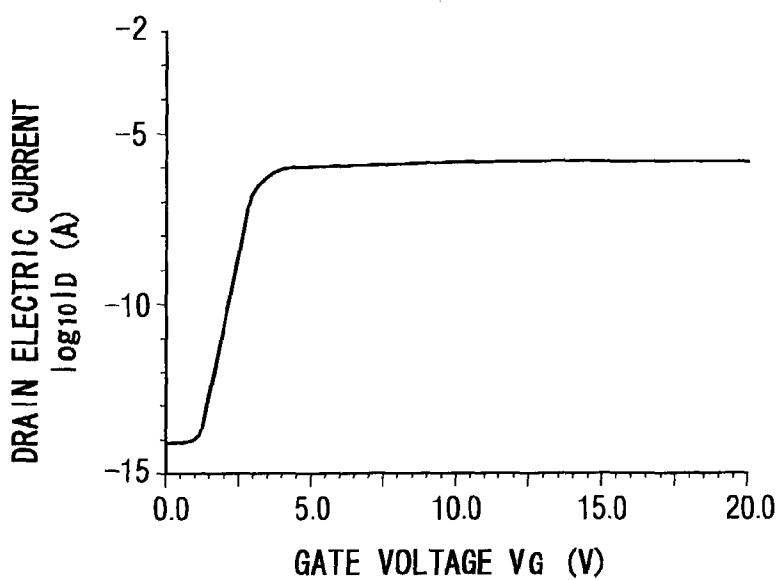


FIG. 31



**FIG. 32**



**FIG. 33**

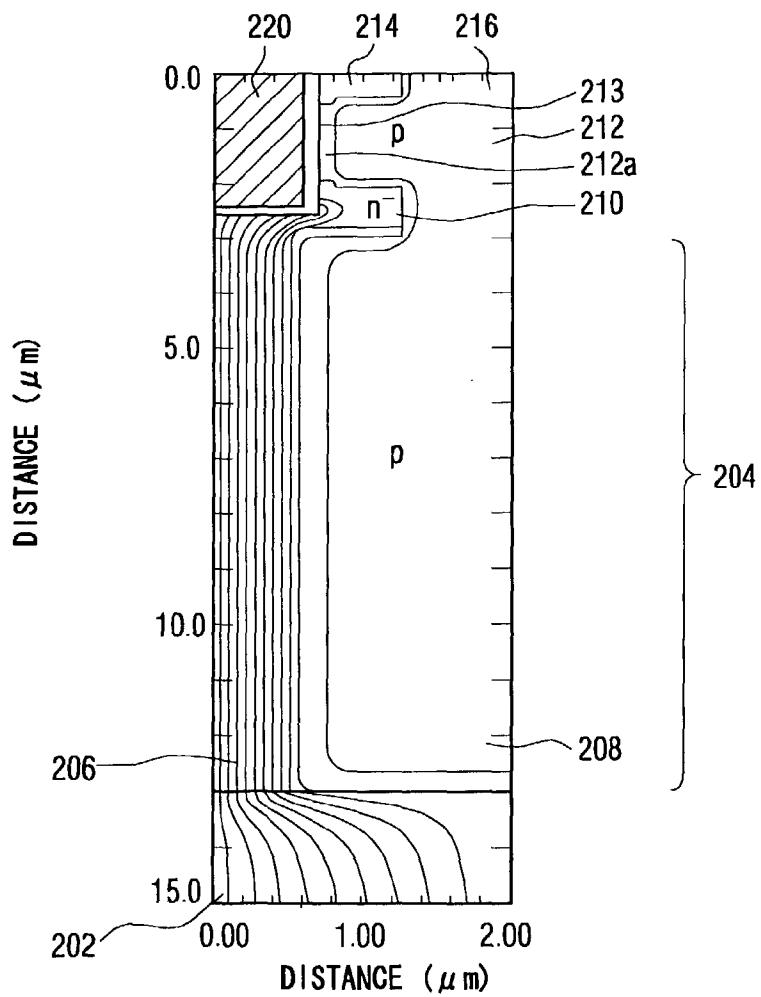


FIG. 34

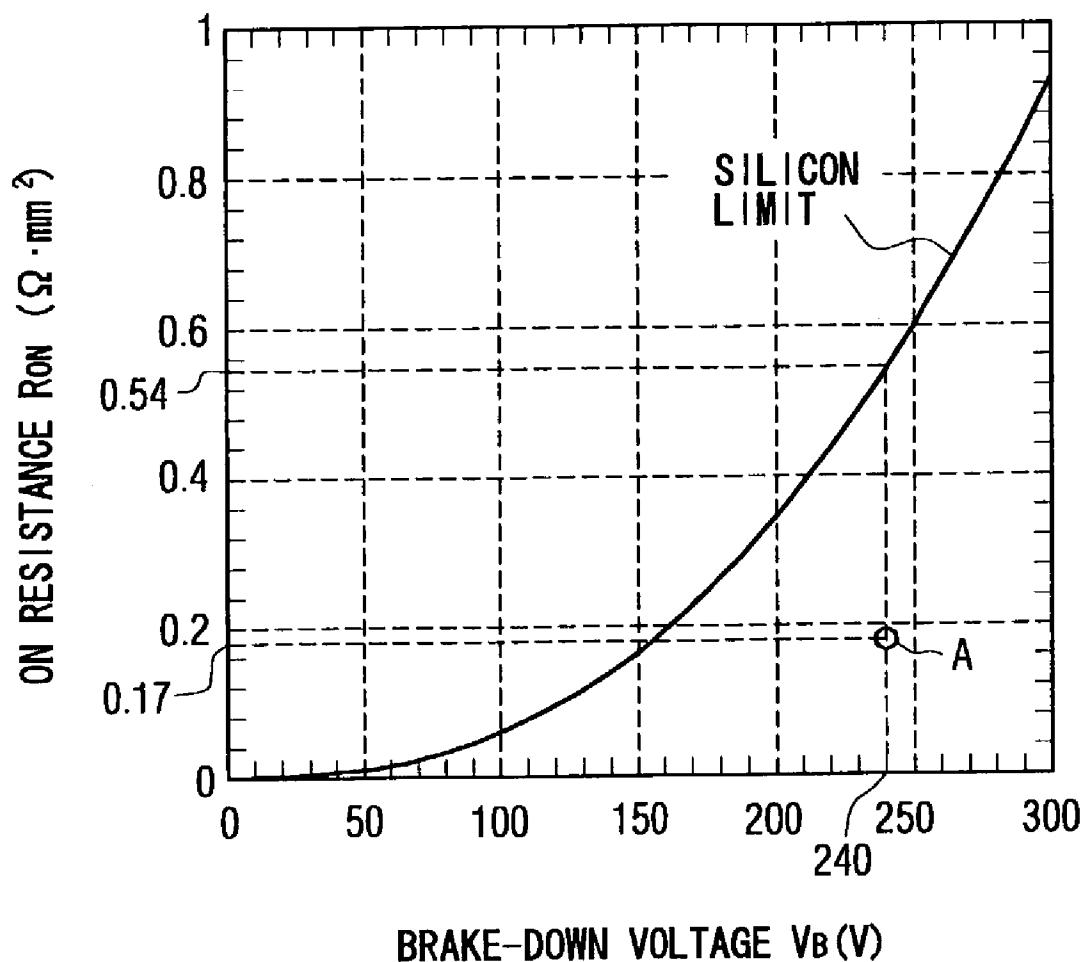


FIG. 35

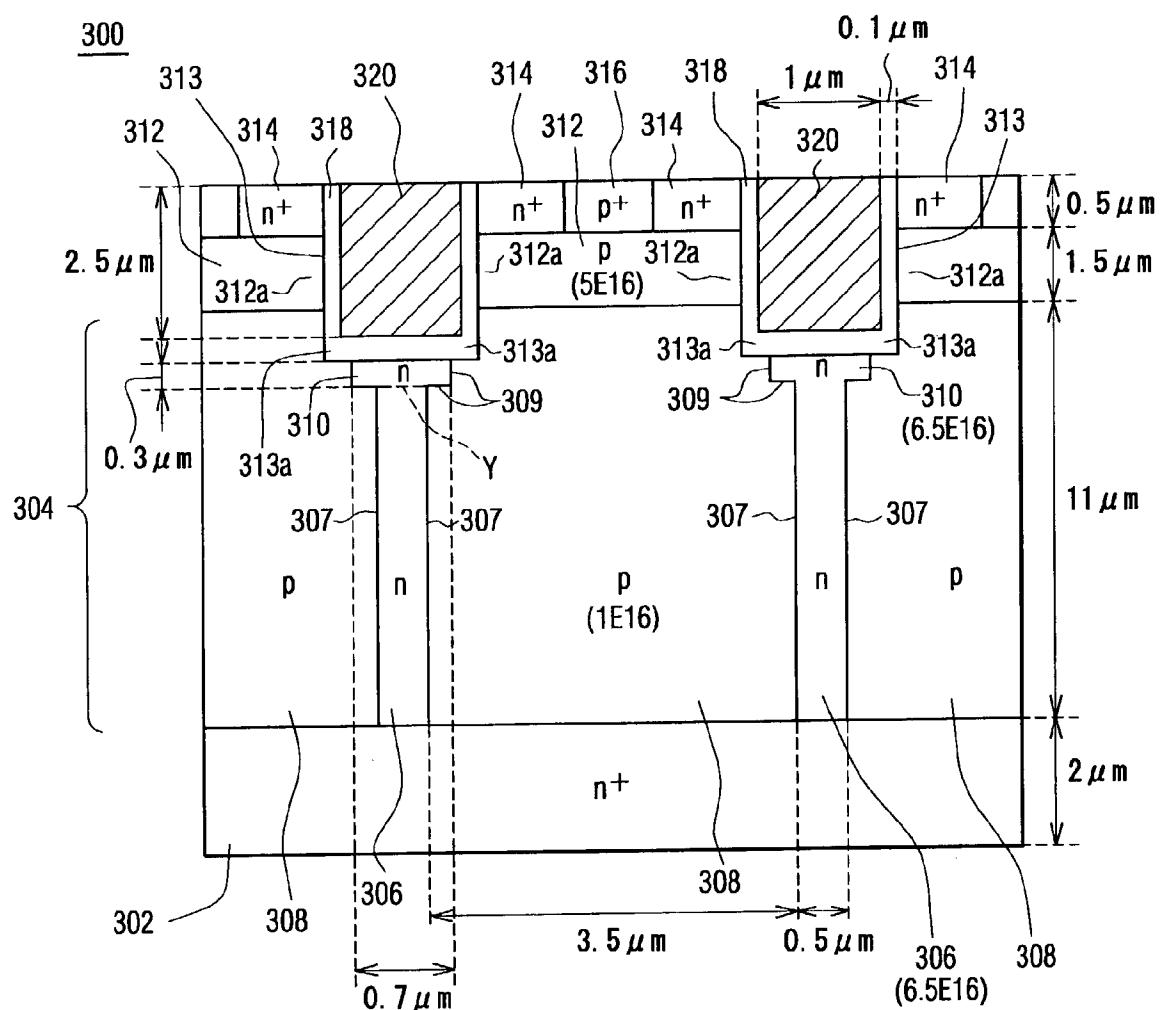


FIG. 36

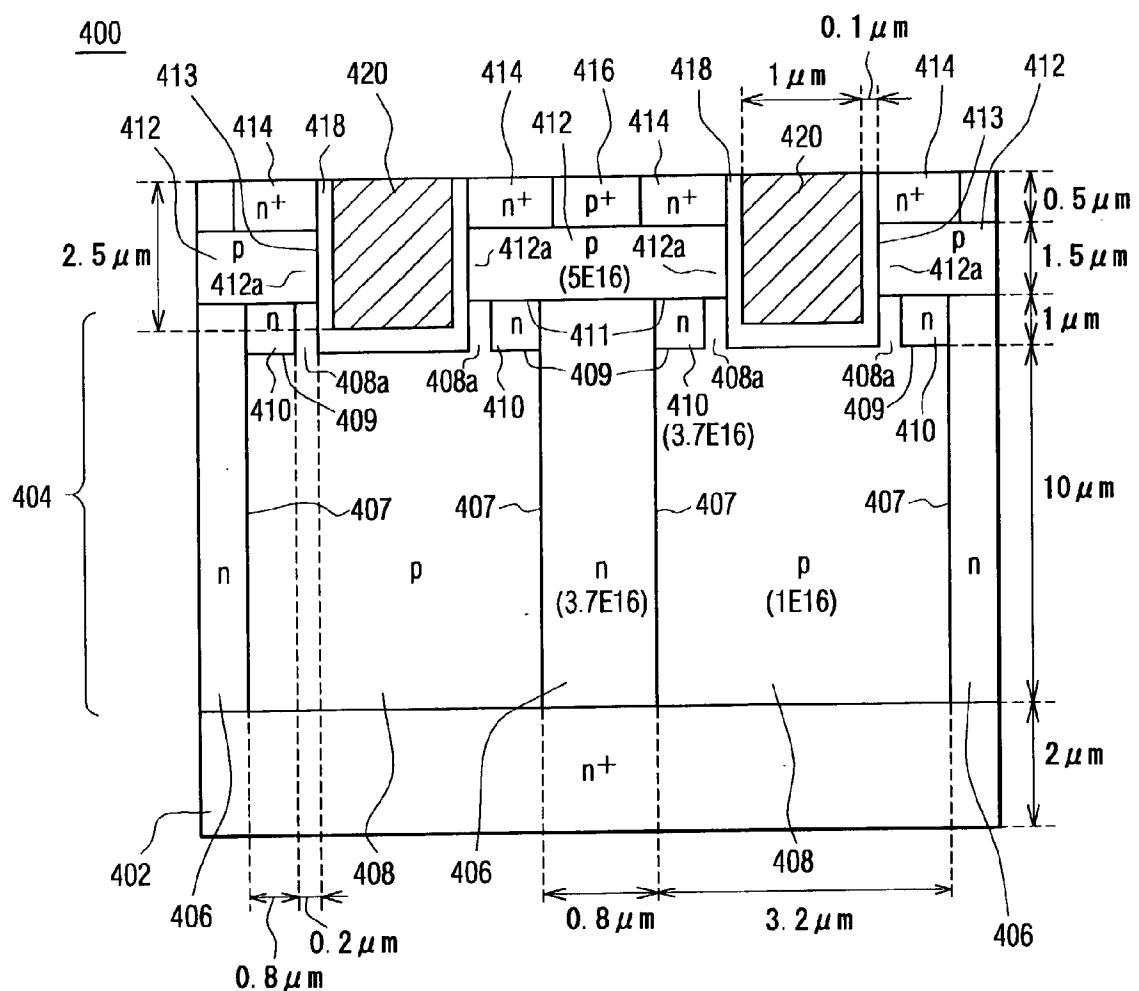
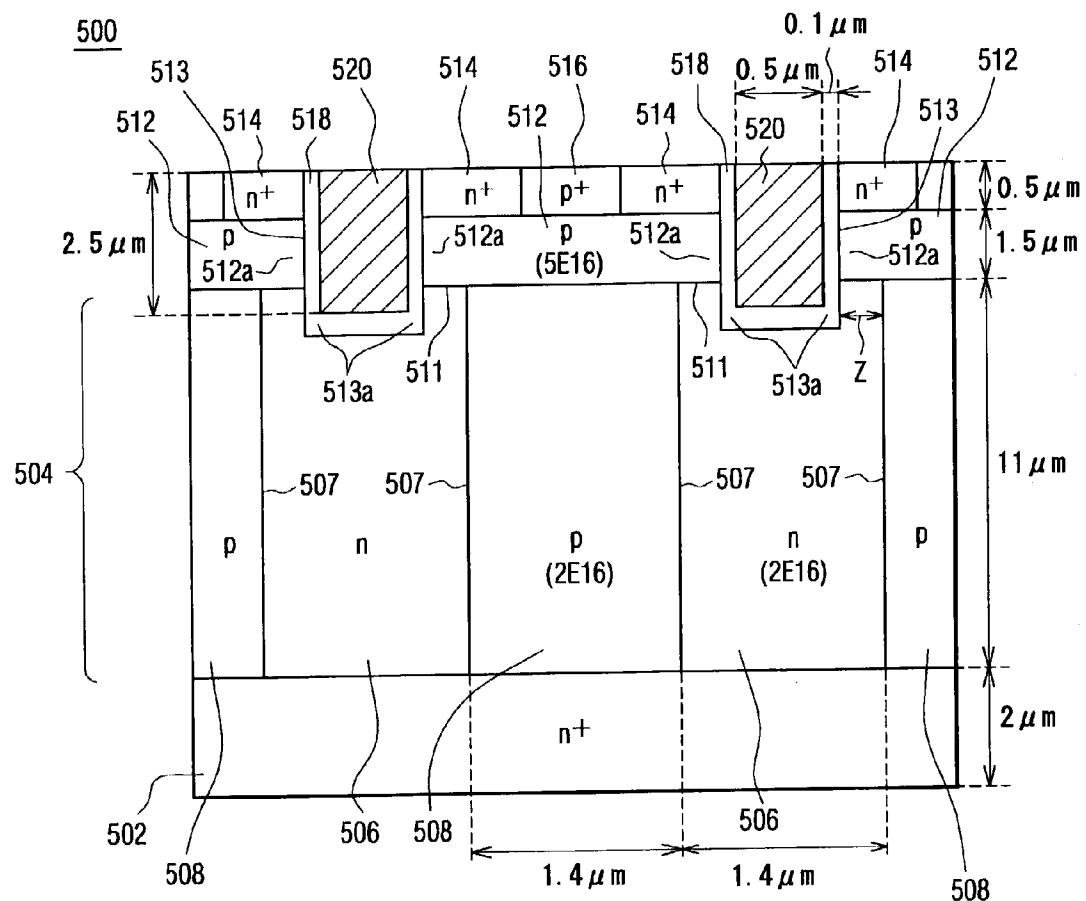
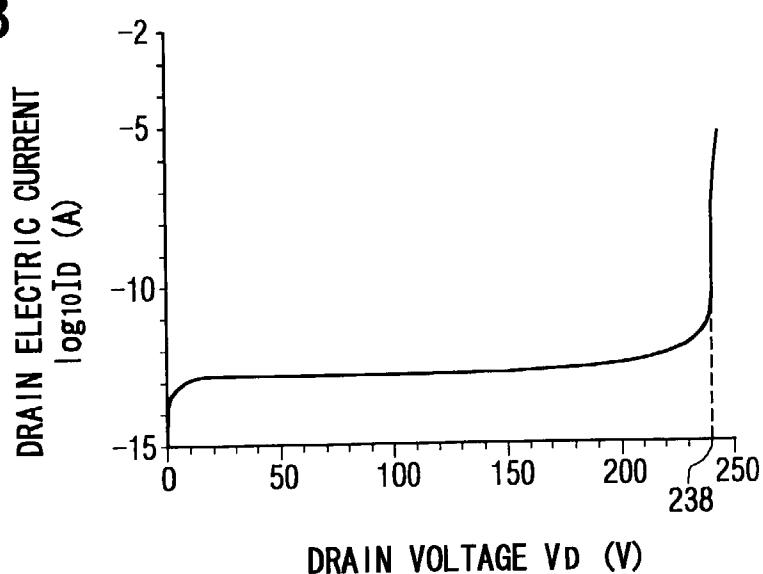


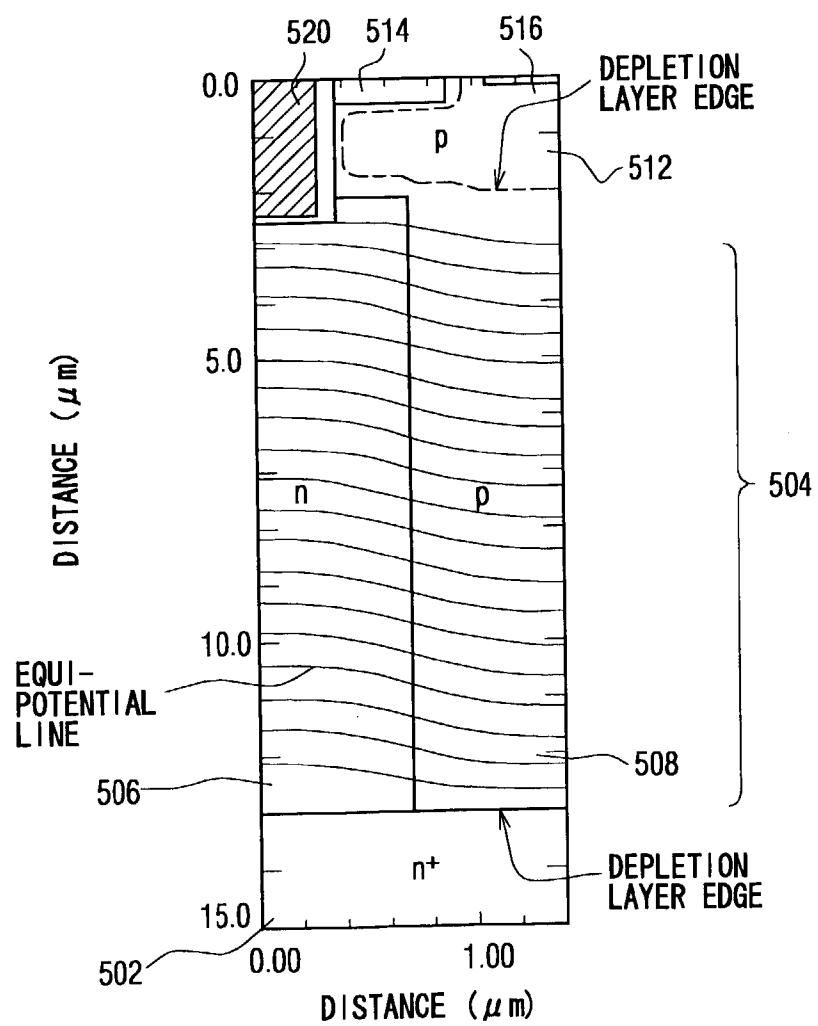
FIG. 37



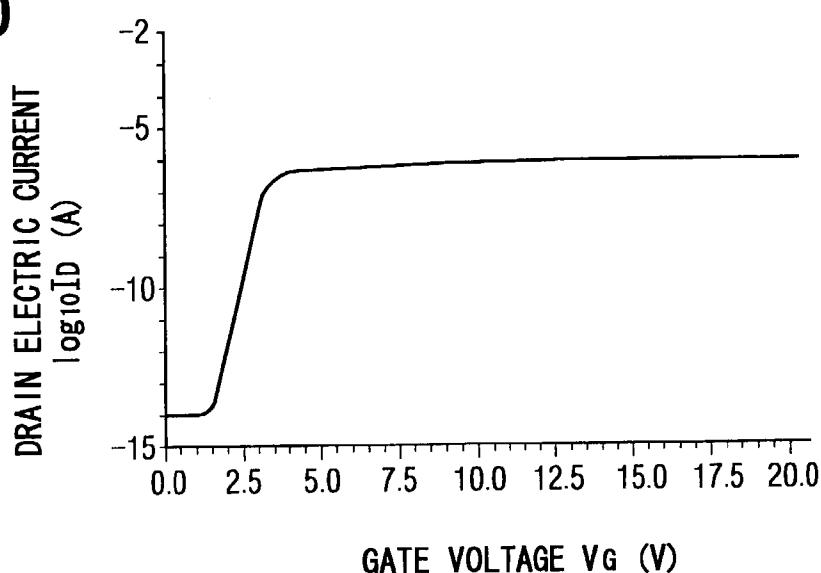
**FIG. 38**



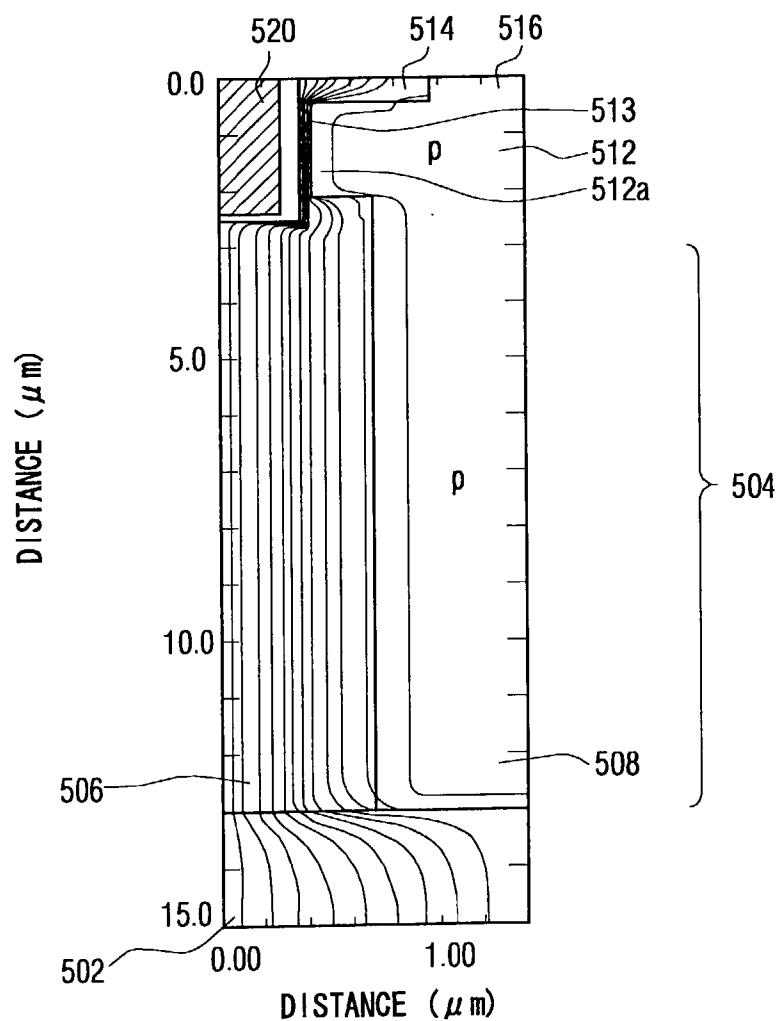
**FIG. 39**



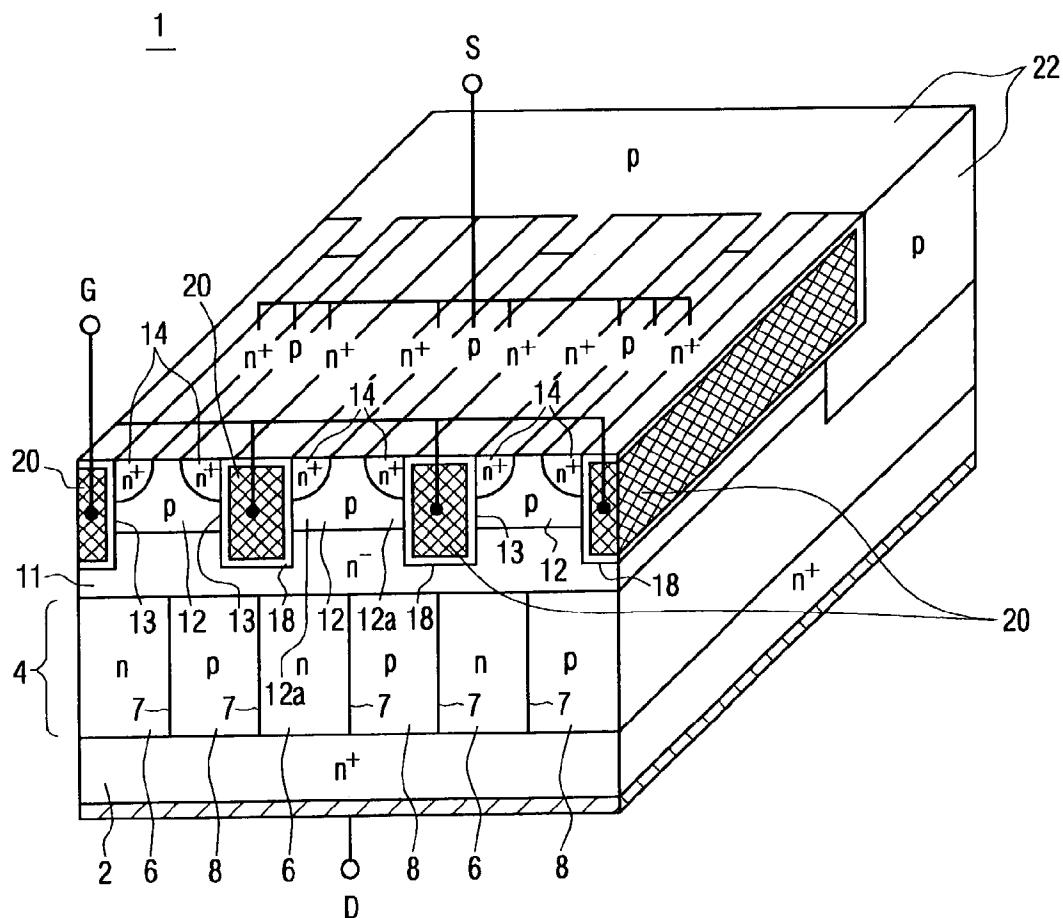
**FIG. 40**



**FIG. 41**



**FIG. 42**  
RELATED ART



## SEMICONDUCTOR DEVICE AND ITS MANUFACTURING METHOD

### FIELD OF THE INVENTION

**[0001]** The present invention relates to a semiconductor device and its manufacturing method. In particular, the semiconductor device is, for instance, used as MOS FET with having high withstand voltage and low ON resistance.

### BACKGROUND OF THE INVENTION

**[0002]** A semiconductor device in JP-A-2000-260984 is shown as a related art in **FIG. 42**. The semiconductor device 1 includes: an n<sup>+</sup> type (first conductivity type) drain region 2; an n type (first conductivity type) drift region 6 connecting with the n<sup>+</sup> type drain region 2; a p type (second conductivity type) body region 12; an n<sup>+</sup> type source region 14 connecting with the p type body region 12; a gate electrode 20 filled with being covered by an insulation film 18 in a gate trench 13 that penetrates the p type body region 12; a p type silicon region (semiconductor region) 8 adjoining the n type drift region 6; and an n<sup>-</sup> type (first conductivity type) silicon region 11 covering the n type drift region 6 and the p type silicon region 8. It further includes a p type silicon region 22 connecting a rear portion of the p type body region 12 and an upper and rear portion of the p type silicon region 8. The n type drift region 6 and the p type silicon region 8 form alternate layers that are orthogonal to the surface of the drain region. The alternate layers constitute super-junction structure 4.

**[0003]** Applying positive electric voltage to the gate electrode 20 in the semiconductor device 1 leads to forming an n type channel 12a in the p type body region 12. A carrier (electron) thereby flows from the n<sup>+</sup> type source region 14 through the n type channel 12a in the p type body region 12 and the n type drift region 6 to the n<sup>+</sup> type drain region 2.

**[0004]** Connecting the gate electrode 20 to ground results in canceling the channel 12a from the p type body region 12. The semiconductor 1 is thereby turned off. In the semiconductor device 1, depletion layers are widened towards the n type drift region 6 and the p type silicon region 8 from a pn junction 7 between the n type drift region 6 and the p type silicon region 8. The n type drift region 6 and the p type silicon region 8 are completely occupied with the depletion layers, so that withstand voltage (break-down voltage) between the n<sup>+</sup> type source region 14 and the n<sup>+</sup> type drain region 2 is attained.

**[0005]** Conventional power MOS structure (not shown) does not include a super-junction structure 4. Withstanding voltage is therefore determined by depletion layers extended from a pn junction between the n type drift region and a p type body region. Typically, impurity concentration is lowered in the n type drift region in comparison with the p type body region, so that the n type drift region is completely occupied with the depletion layer. Required withstand voltage is thereby attained.

**[0006]** When the drift region is formed of the super-junction structure 4 as shown in **FIG. 42**, the depletion layers extend towards the n type drift region 6 from the pn junctions 7 that are located in both sides of the drift region 6. To attain a certain withstand voltage, a semiconductor

device with the super-junction structure 4 can include a more impurity in the n type drift region 6 than a semiconductor without the super-junction structure 4. This results in obtaining a low ON-resistance semiconductor device with having the same certain withstand voltage.

**[0007]** In manufacturing a semiconductor device, a mask for forming the gate trench 13 may shift horizontally (in parallel with the surface of the drain region 2), or etching for forming the gate trench 13 may be practiced more deeply (orthogonally to the surface of the drain region 2) than a required depth. These manufacturing problems arise even at the present day when micro-fabrication is much progressed. In this case, without forming the n<sup>-</sup> type silicon region 11, the trench may reach the n type drift region 6 or the p type silicon region 8 through a bottom of the p type body region 12. Here, the carrier that passes through the n type channel in the p type body region forms a channel also in the p type silicon region 8 due to MOS effect before reaching the n type drift region 6. Channel resistance in the p type silicon region 8 is thereby increased, so that the ON resistance of the semiconductor device 1 is increased.

**[0008]** In the above semiconductor device 1, disposing the n<sup>-</sup> type silicon region covering the n type drift region 6 and the p type silicon region 8 prevents the ON resistance from increasing due to the manufacturing problems.

**[0009]** However, when the n<sup>-</sup> type silicon region 11 thoroughly isolates the p type silicon region 8 from the p type body region 12, the p type silicon region 8 is in floating electric potential. In this condition, when, during withstand voltage, positive voltage is applied to the n<sup>+</sup> type drain region 2 and the n<sup>+</sup> type source region is connected to ground, voltage for extending the depletion layers towards the n type drift region 6 and the p type silicon region 8 may not be sufficiently applied to the pn junction between them. A characteristic of withstand voltage may thereby become unstable. For preventing the p type silicon region 8 from remaining in the floating electric potential, the p type silicon region 22 is provided in a rear portion of the semiconductor device 1. It is for connecting an upper rear portion of the p type silicon region 8 and a rear portion of the p type body region 12 as shown in **FIG. 42**.

**[0010]** Here, the p type body region 12 and the p type silicon region 8 must be electrically connected through the silicon region 22 via a long electric current passage. During withstand voltage, a virtual pnp transistor is formed among the p type body region 12, the n<sup>-</sup> type silicon region 11, and the p type silicon region 8. This pnp transistor sometimes shifts to an ON state due to voltage drop deriving from the long electric current passage. As a result, during withstand voltage, a leak current may flow from the p type silicon region 8 through the n<sup>-</sup> type silicon region 11 to the p type body region 12.

### SUMMARY OF THE INVENTION

**[0011]** It is an object of the present invention to provide a semiconductor device having a shorten electric current passage between a second semiconductor region and a body region. This is realized under condition where an ON resistance is prevented from increasing due to horizontal misalignment of masking or vertical misalignment of depth control during forming a gate trench. Furthermore, here, the

second semiconductor region is not moved to floating electric potential, so that a characteristic of withstand voltage is maintained to be stable.

[0012] To achieve the above object, a semiconductor device includes: a first-conductivity type drain region; a first-conductivity type drift region that connects with the drain region; a second-conductivity type body region; a first-conductivity type source region that connects with the body region; a gate electrode that is provided, with being covered by a gate insulation film, in a gate trench that penetrates the body region. The semiconductor device further includes: a first semiconductor region that is a first-conductivity type and provided between the drift region and the body region; and a second semiconductor region that is a second-conductivity type and connects with the drift region and the body region.

[0013] This structure prevents an ON resistance from increasing due to horizontal misalignment of masking or vertical misalignment of depth control during forming a gate trench. Since the second semiconductor region directly connects with the body region, the second semiconductor region is not moved to floating electric potential. Furthermore an electric current passage can be shortened between the second semiconductor region and the body region. No necessity of independently disposing a p type silicon region for connecting the second semiconductor region and the body region leads to realization of downsizing, weight saving, and high integration in the semiconductor device.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The above and other objects, features and advantages of the present invention will become more apparent from the following detailed description made with reference to the accompanying drawings. In the drawings:

[0015] FIG. 1 is a sectional view of a semiconductor device according to a first embodiment of the present invention;

[0016] FIG. 2 is a view explaining part (1) of a first manufacturing method of the semiconductor device according to the first embodiment;

[0017] FIG. 3 is a view explaining part (2) of the first manufacturing method of the semiconductor device according to the first embodiment;

[0018] FIG. 4 is a view explaining part (3) of the first manufacturing method of the semiconductor device according to the first embodiment;

[0019] FIG. 5 is a view explaining part (4) of the first manufacturing method of the semiconductor device according to the first embodiment;

[0020] FIG. 6 is a view explaining part (5) of the first manufacturing method of the semiconductor device according to the first embodiment;

[0021] FIG. 7 is a view explaining part (6) of the first manufacturing method of the semiconductor device according to the first embodiment;

[0022] FIG. 8 is a view explaining part (7) of the first manufacturing method of the semiconductor device according to the first embodiment;

[0023] FIG. 9 is a view explaining part (8) of the first manufacturing method of the semiconductor device according to the first embodiment;

[0024] FIG. 10 is a view explaining part (1) of a second manufacturing method of the semiconductor device according to the first embodiment;

[0025] FIG. 11 is a view explaining part (2) of the second manufacturing method of the semiconductor device according to the first embodiment;

[0026] FIG. 12 is a view explaining part (3) of the second manufacturing method of the semiconductor device according to the first embodiment;

[0027] FIG. 13 is a view explaining part (1) of a third manufacturing method of the semiconductor device according to the first embodiment;

[0028] FIG. 14 is a view explaining part (2) of the third manufacturing method of the semiconductor device according to the first embodiment;

[0029] FIG. 15 is a view explaining part (3) of the third manufacturing method of the semiconductor device according to the first embodiment;

[0030] FIG. 16 is a view explaining part (4) of the third manufacturing method of the semiconductor device according to the first embodiment;

[0031] FIG. 17 is a view explaining part (1) of a fourth manufacturing method of the semiconductor device according to the first embodiment;

[0032] FIG. 18 is a view explaining part (2) of the fourth manufacturing method of the semiconductor device according to the first embodiment;

[0033] FIG. 19 is a view explaining part (1) of a fifth manufacturing method of the semiconductor device according to the first embodiment;

[0034] FIG. 20 is a view explaining part (2) of the fifth manufacturing method of the semiconductor device according to the first embodiment;

[0035] FIG. 21 is a view explaining part of a sixth manufacturing method of the semiconductor device according to the first embodiment;

[0036] FIG. 22 is a view explaining part (1) of a seventh manufacturing method of the semiconductor device according to the first embodiment;

[0037] FIG. 23 is a view explaining part (2) of the seventh manufacturing method of the semiconductor device according to the first embodiment;

[0038] FIG. 24 is a view explaining part (1) of an eighth manufacturing method of the semiconductor device according to the first embodiment;

[0039] FIG. 25 is a view explaining part (2) of the eighth manufacturing method of the semiconductor device according to the first embodiment;

[0040] FIG. 26 is a view explaining part (1) of a ninth manufacturing method of the semiconductor device according to the first embodiment;

[0041] **FIG. 27** is a view explaining part (2) of the ninth manufacturing method of the semiconductor device according to the first embodiment;

[0042] **FIG. 28** is a view explaining part (3) of the ninth manufacturing method of the semiconductor device according to the first embodiment;

[0043] **FIG. 29** is a sectional view of a semiconductor device according to a second embodiment;

[0044] **FIG. 30** is a diagram showing a characteristic of withstanding voltage of the semiconductor device according to the second embodiment;

[0045] **FIG. 31** is a diagram showing voltage distribution at drain voltage of 200 V of the semiconductor device according to the second embodiment;

[0046] **FIG. 32** is a diagram showing ON characteristic of the semiconductor device according to the second embodiment;

[0047] **FIG. 33** is a diagram showing electric current distribution at gate voltage of 15 V of the semiconductor device according to the second embodiment;

[0048] **FIG. 34** is a diagram showing characteristic of brake-down voltage and ON resistance of the semiconductor device according to the second embodiment;

[0049] **FIG. 35** is a sectional view of a semiconductor device according to a third embodiment;

[0050] **FIG. 36** is a sectional view of a semiconductor device according to a fourth embodiment;

[0051] **FIG. 37** is a sectional view of a semiconductor device according to a fifth embodiment;

[0052] **FIG. 38** is a diagram showing a characteristic of withstanding voltage of the semiconductor device according to the fifth embodiment;

[0053] **FIG. 39** is a diagram showing voltage distribution at drain voltage of 200 V of the semiconductor device according to the fifth embodiment;

[0054] **FIG. 40** is a diagram showing ON characteristic of the semiconductor device according to the fifth embodiment;

[0055] **FIG. 41** is a diagram showing electric current distribution at gate voltage of 15 V of the semiconductor device according to the fifth embodiment; and

[0056] **FIG. 42** is a perspective view showing a semiconductor device of a related art.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0057] (First Embodiment)

[0058] A vertical semiconductor device **100** of a first embodiment of the present invention is shown in a sectional view in **FIG. 1**. A width A shown in a lower area of **FIG. 1** shows a unit structure that is repeatedly formed in a horizontal direction (from side to side) of **FIG. 1**.

[0059] The semiconductor device **100** forms metal oxide semiconductor (MOS) field effect transistor (FET) structure of a U trench type (U-shaped gate trench **113**). The semi-

conductor device **100** is used for a motor of a vehicle, or a power converter or power control of electrical appliances for home use.

[0060] The semiconductor device **100** includes a drain region **102**, a drift region **106**, a silicon region **108**, a body region **112**, an upper silicon region **110**, a source region **114**, and a gate **120**.

[0061] The drain region **102** is an n<sup>+</sup> type (first conductivity type). It is 2  $\mu\text{m}$  thick (vertical direction (from bottom to top) in **FIG. 1**).

[0062] The drift region **106** is an n type (first conductivity type) and connects with the n<sup>+</sup> type drain region **102**. At an ON state of the semiconductor device **100**, a carrier (electron) flows through the n type drift region **106**. During withstanding voltage, the drift region **106** is occupied with a depletion layer along with the silicon region **108**. The n type drift region **106** has an n type impurity of 2.8 E 16 cm<sup>-3</sup> and is 1  $\mu\text{m}$  wide (horizontal direction in **FIG. 1**) and 10  $\mu\text{m}$  thick. These values are selected for enabling the n type drift region **106** to be occupied with the depletion layer during withstanding required voltage.

[0063] The silicon region **108** is a p type (second conductivity type) and connects with the n type drift region **106**. During withstanding voltage, the silicon region **108** is occupied with the depletion layer along with the drift region **106**. The p type silicon region **108** has a p type impurity of 1 E 16 cm<sup>-3</sup> and is 3  $\mu\text{m}$  wide and 10  $\mu\text{m}$  thick. These values are selected for enabling the p type silicon region **108** to be occupied with the depletion layer during withstanding required voltage.

[0064] The n type drift region **106** and the p type silicon region **108** form alternate layers that are orthogonal to the surface of the drain region **102** and parallel to a carrier passage where the carrier flows. The alternate layers form so called super-junction structure **104**. In other words, the n type drift region **106** and the p type silicon region **108** are jointed with a pn junction. The pn junctions are horizontally-repeatedly disposed at intervals in the (vertical) alternate layers.

[0065] The body region **112** is a p type and connects with the p type silicon region **108**. During the ON state of the vertical semiconductor device **100**, an n type channel is formed in a region **112a** inside the p type body region **112**. The p type body region **112** has a p type impurity of 5 E 16 cm<sup>-3</sup> and is 1.5  $\mu\text{m}$  thick. A body contact region **116** that is 0.5  $\mu\text{m}$  thick and an p<sup>+</sup> type is formed on the surface of the p type body region **112**.

[0066] An upper silicon region **110** of an n type is disposed in a region that almost includes the carrier passage between the n type drift region **106** and the p type body region **112**. The n type upper silicon region **110** is disposed between an upper plane (dotted line Y in **FIG. 1**) of the n type drift region **106** and a lower plane of the p type body region **112**.

[0067] The n type upper silicon region **110** connects with the n type drift region **106**. In this embodiment, the n type upper silicon region **110** and the n type drift region **106** are formed as one united deposited layer (film) by a first manufacturing method explained later. The n type upper silicon region has an n type impurity of 2.8 E 16 cm<sup>-3</sup>, which is similar to that of the n type drift region **106**. However, the

n type impurity concentration can be different between the n type upper silicon region 110 and the n type drift region 106. For instance, the n type upper silicon region 110 can have the n type impurity of  $1 \text{ E } 16 \text{ cm}^{-3}$ .

[0068] The n type upper silicon region 110 connects with p type body region 112 and the region 112a where the n type channel is formed inside the p type body region 112. The n type upper silicon region 110 is disposed between the n type drift region 106 and the bottom of the gate trench 113. The n type upper silicon region 110 is  $3 \mu\text{m}$  wide and  $1 \mu\text{m}$  thick, and wider than the gate trench 113. The n type upper silicon region 110 has a broader width than the n type drift region 106 and the gate trench 113 by almost same length in each of both ends of the width. The n type upper silicon region 110 surrounds a bottom of the gate trench 113 and lower end portions 113a of the side walls of the gate trench 113.

[0069] The n type upper silicon region 110 is favorably not less than  $0.5 \mu\text{m}$  by considering vertical control misalignment in depth of the gate trench 113 through anisotropic etching. By contrast, the n type upper silicon region 110 should be enough thin (in detail, not greater than  $1.5 \mu\text{m}$ ) so that the n type upper silicon region 110 is thoroughly or nearly occupied with the depletion layer during withstanding voltage. In detail, it should be not greater than  $1.5 \mu\text{m}$  thick although the thickness is affected by required withstanding voltage and impurity concentration around the own region.

[0070] The source region 114 of an n<sup>+</sup> type is  $0.5 \mu\text{m}$  thick and connects with the surface of the p type body region 112.

[0071] The gate electrode 120 is filled, with being covered with the U-shaped gate insulation film 118, in the gate trench 113 that penetrates the p type body region 112. The gate electrode 120 is  $1 \mu\text{m}$  wide and  $2.5 \mu\text{m}$  deep (thick). The gate insulation film 118 is  $0.1 \mu\text{m}$  wide that is determined based on required threshold voltage.

[0072] Operation of the vertical semiconductor device 100 of the first embodiment will be explained below. The n<sup>+</sup> type drain region 102 is applied the positive voltage to while the n<sup>+</sup> type source region 114 and the p<sup>+</sup> type body contact region 116 are connected to ground. Here, when the vertical semiconductor device 100 is shifted into an ON state or the gate electrode 120 is applied positive voltage to, an electron inside the p type body region 112 congregates in the region 112a to form the n type channel. The electron that is supplied from the n<sup>+</sup> type source region 114 thereby flows through the n type channel 112a, the n type upper silicon region 110, the n type drift region 106 to reach the n<sup>+</sup> type drain region 102. In other words, at the ON state of the vertical semiconductor device 100, electric current flows from the drain region 102 to the source region 114.

[0073] In the above structure of the vertical semiconductor device 100, the electron flows out from the n type channel 112a through the n type upper silicon region 110 (in particular a region along the gate trench 113) and then the n type drift region 106. It does not flow into the p type silicon region 108, so that an n type channel is not formed in the p type silicon region 108. This prevents the ON resistance from increasing. The above structure is effectively used for a semiconductor device having withstanding voltage of not greater than 200 V. In this semiconductor device, a channel resistance of the n type channel formed inside the p type silicon region 108 is much contributory to overall ON resistance of the semiconductor device.

[0074] When withstanding voltage is measured between the n<sup>+</sup> type source region 114 and the n<sup>+</sup> type drain region 102, voltage applied to the n<sup>+</sup> type drain region 102 is gradually increased from 0 V while applying 0 V to the gate electrode 120 and the n<sup>+</sup> type source region 114. Here, with increasing applied voltage, the depletion layers are widened from three pn junctions 107, 109, and 111 towards the regions 106, 108, 110, and 112. At required withstanding voltage, the regions 106 and 108 are thoroughly occupied with the depletion layers. Regions where the super-junction structure 104 is formed are completely occupied with the depletion layers, so that high withstanding voltage can be attained. Furthermore, the p type silicon region 108 connects with the p type body region 112, and the P<sup>+</sup> type body contact region 116 is formed on the surface of the p type body region 112. The p type silicon region 108 is thereby not in a state of floating electric potential. This results in stabilizing a characteristic of the withstanding voltage.

[0075] Thus, in the vertical semiconductor device 100 of the first embodiment, the p type silicon region 22 of the related art shown in FIG. 42 is unnecessary. The p type silicon region 108 shown in FIG. 1 is not in the state of floating electric potential without disposing the p type silicon region 22 for connecting the p type silicon region 8 and the p type body region 12 in the related art. The characteristic of the withstanding voltage is thereby stabilized. The p type silicon region 108 directly connects with the p type body region 112, so that an electric current passage can be shortened between the p type silicon region 108 and the p type body region 112. No necessity of independently disposing the p type silicon region for connecting as shown in FIG. 42 leads to realization of downsizing, weight saving, and high integration in the vertical semiconductor device 100.

[0076] Disposing the n type upper silicon region 110 having a broader width enables the n type drift region 106 to maintain a narrow width. Impurity concentration of the n type drift region 106 can be thereby high while simultaneously maintaining the high withstanding voltage. This results in realizing a semiconductor device that has low ON resistance while maintaining the high withstanding voltage.

[0077] Simulation result of the characteristic of the vertical semiconductor device 100 of the first embodiment will be explained below. Here, the impurity concentrations are as follows: the n type drift region 106 has an n type impurity of  $3.0 \text{ E } 16 \text{ cm}^{-3}$ ; the p type silicon region 108 has a p type impurity of  $3.0 \text{ E } 16 \text{ cm}^{-3}$ ; and the n type upper silicon region 110 has an n type impurity of  $2.8 \text{ E } 16 \text{ cm}^{-3}$ . The p type silicon region 108 has width of  $1 \mu\text{m}$ . These values of the above impurity concentrations and the thickness are different from the values explained in FIG. 1. Under the above conditions, the withstanding voltage is about 235 V, while the ON resistance is about  $0.078 \Omega \text{ mm}^2$  at  $V_G=15 \text{ V}$ .

[0078] (First Manufacturing Method Instance)

[0079] Various manufacturing methods for the first embodiment will be explained. As shown FIG. 2, an n type layer 106 is deposited over an n<sup>+</sup> type substrate (n<sup>+</sup> type drain region) 102, for instance, with an epitaxial growth method. A trench 106a is formed for penetrating the n type layer 106 to reach the n<sup>+</sup> type drain region 102 with an anisotropic etching (e.g., reactive ion etching (RIE)) through masking by resist (photo sensitive film) as shown in FIG. 3.

As a result, the n type layer 106 becomes an n type drift region 106.

[0080] A p type layer 108 is then deposited, for instance with the epitaxial growth method, inside the trench 106a to form alternate layers of the n type layer 106 and the p type layer 108 and, consecutively an overhead p type layer 108 over the alternate layers as shown in **FIG. 4**.

[0081] The overhead p type layer 108 is polished and planarized till an upper plane of the n type drift region 106, for instance with chemical mechanical polishing (CMP) as shown in **FIG. 5**.

[0082] An n type layer 110 having thickness A is then deposited, for instance with the epitaxial growth method, as shown in **FIG. 6**. The thickness A of the n type layer 110 is equal to total thickness of the n type upper silicon region 110 and the p type body region 112. A p type impurity is added, for instance with ion implantation, to a predetermined region inside the n type layer 110. The predetermined region is a central portion of a region disposed over the p type silicon region 108. As a result, a p type connecting region 115 is formed, and an n type upper silicon region 110 that is partitioned by the p type connecting region 115 is simultaneously formed as shown in **FIG. 7**. Also as shown in **FIG. 7**, a p type impurity is furthermore added, for instance with ion implantation, into an overall upper region of the n type layer 110, so that a p type layer 112 is formed for constituting a p type body region. In the above ion plantation, velocity or amount of the ion plantation is controlled for attaining thickness B of the n type upper silicon region 110 and thickness C of the p type connecting region 115.

[0083] As shown in **FIG. 8**, a gate trench 113 is formed for penetrating the p type layer 112 to reach the n type upper silicon region 110, for instance with the anisotropic etching (RIE or the like) through masking, by the resist, over a central region of the n type upper silicon region 110.

[0084] As shown in **FIG. 9**, a thin gate insulation film 118 of U-shaped silicon oxide film is then deposited along side walls and a bottom of the gate trench 113, for instance with chemical vapor deposition (CVD) method. Thereafter a gate electrode 120 of poly-silicon is deposited in the U-shaped gate insulation film 118 inside the gate trench 113, for instance with the CVD method. Finally, as shown in **FIG. 1**, an n<sup>+</sup> type source region 114 is formed on the surface of the body region 112 with the ion plantation, e.g., using arsenic or phosphorus. A p<sup>+</sup> type body contact region 116 is formed on the surface of the body region 112 with the ion plantation, e.g., using boron.

[0085] Through the above manufacturing steps, the vertical semiconductor device 100 of the first embodiment is manufactured.

[0086] In the above first manufacturing method instance, the trench 106a, the gate trench 113 or the like is formed with the anisotropic etching (RIE or the like). However, other types of a dry etching method and a wet etching method can be adopted. Although the p type layer 108 is planarized with the CMP, it can be planarized with an etch back or the like. Although addition of the impurity is done with the ion plantation, a thermal diffusion method or the like can be adopted. Although the gate insulation film 118 is formed of the silicon oxide, it can be formed of high

dielectric insulation film such as silicon nitride film, SrTiO<sub>3</sub> (STO) film, or BaSrTiO<sub>3</sub> (BST) film. The gate insulation film 118 is deposited inside the gate trench 113 with the CVD. However, it can be formed through thermal treatment using thermal oxidation applied to the side walls (body region 112) and the bottom (upper silicon region 110) of the gate trench 113. Although the gate electrode 120 is formed of the poly-silicon, it can be formed of amorphous silicon layer, monocrystal silicon layer, or the like. These modifications can be also directed to other manufacturing method instances to be explained later.

[0087] In the first manufacturing method instance, as shown in **FIG. 8**, the gate trench 113 is formed, with the anisotropic etching or the like, inside the n type upper silicon region 110 that is previously formed as shown in **FIG. 7**. The ON resistance is thereby prevented from increasing due to the horizontal misalignment of masking and vertical misalignment of depth control during forming the gate trench 113.

[0088] Namely, as long as horizontal misalignment is within the width of the n type upper silicon region 110 shown in **FIG. 8**, the n type channel is hardly formed in the p type silicon region 108 during the ON state. Even if the misalignment exceeds the one end of the width of the n type upper silicon region 110, the n type channel is much less formed in the p type silicon region 108 in comparison with a semiconductor device having no n type upper silicon region 110.

[0089] Similarly, as long as vertical misalignment is within the depth (thickness) of the n type upper silicon region 110 shown in **FIG. 8**, the n type channel is hardly formed in the p type silicon region 108 during the ON state. Even if the misalignment exceeds the one end of the depth of the n type upper silicon region 110, the n type channel is much less formed in the p type silicon region 108 in comparison with the semiconductor device having no n type upper silicon region 110.

[0090] (Second Manufacturing Method Instance)

[0091] In a second manufacturing method instance, the steps shown in FIGS. 2 to 5 in the first manufacturing method instance are similarly operated. As shown in **FIG. 10**, an n type layer 110 having thickness C is then deposited using the epitaxial growth or the like. The thickness C is only for the n type upper silicon region 110, while the thickness A shown in **FIG. 5** of the first manufacturing method instance is for not only the n type silicon region 110 but also the p type body region 112.

[0092] As shown in **FIG. 11**, a p type impurity is added into the n type layer 110 over a central region of the width of the p type silicon region 108 with the ion plantation or the like. The p type connecting region 115 is thereby formed and the n type silicon region 110 partitioned by the p type connecting region 115 is simultaneously formed.

[0093] As shown in **FIG. 12**, a p type layer 112 having thickness B is then deposited over the p type connecting region 115 and the n type silicon region 110 with the epitaxial growth or the like. Subsequent steps are similar to that of the steps shown in FIGS. 8 and 9 of the first manufacturing method instance.

[0094] In this manufacturing method instance, as shown in **FIG. 11**, the p type impurity is added to the n type layer 110.

However, without adding the p type impurity, a trench is once formed over the central region of the width of the p type silicon region **108** and the p type layer can be thereafter deposited inside the trench and on the n type silicon region **110**.

[0095] Furthermore, in this manufacturing method instance, the n type layer **110** having thickness C is deposited, and then the p type impurity is added for forming the p type connecting region **115** and the n type upper silicon region **110**.

[0096] However, instead of forming the n type layer, a p type layer having thickness C can be formed firstly. An n type impurity is then added, with the ion plantation or the like, to a predetermined region of the deposited p type layer over the n type drift region **106**. The predetermined region has wider than the drift region **106**. The n type upper silicon region **110** is thereby formed and the p type connecting region **115** partitioned by the n type upper silicon region **110** is simultaneously formed.

[0097] (Third Manufacturing Method Instance)

[0098] In a third manufacturing method instance, as shown in **FIG. 13**, a p type layer **108** is formed over an n<sup>+</sup> type substrate (n<sup>+</sup> type drain region) **102** with the epitaxial growth or the like.

[0099] As shown in **FIG. 14**, a trench **108a** is formed for penetrating the p type layer **108** to reach the n<sup>+</sup> type drain region **102** through masking of the resist with the anisotropic etching (RIE or the like) or the like. The p type layer **108** becomes the p type silicon region **108**.

[0100] As shown in **FIG. 15**, with the epitaxial growth or the like, an n type layer **106** is then deposited inside the trench **108a** to form alternate layers of the n type layer **106** and the p type layer **108** and consecutively an overhead n type layer **106** over the alternate layers.

[0101] As shown in **FIG. 16**, the n type layer **110** is planarized with the CMP or the like till the n type layer **110** still has thickness C over the alternate layers. Thereafter, the steps shown in **FIGS. 11 and 12** of the second manufacturing method instance are used and then the steps shown in **FIGS. 8 and 9** of the first manufacturing method instance are used.

[0102] (Fourth Manufacturing Method Instance)

[0103] In a fourth manufacturing method instance, the steps shown in **FIGS. 2 to 5** of the first manufacturing method instance are similarly used. However, in this manufacturing method instance, super-junction structure of the p type layer **108** and the n type layer **106** is formed for being thicker by thickness C than that of **FIG. 5**.

[0104] As shown in **FIG. 18**, an n type impurity is added with the ion implantation or the like to a region corresponding to thickness C of **FIG. 17**. Here, a p type impurity is then added to a region of the n type impurity implanted layer over a central region of the p type layer **108**. A p type connecting region **115** is thereby formed, and an n type upper silicon region **110** partitioned by the p type connecting region **115** is simultaneously formed. Subsequent steps are similar to the steps shown in **FIG. 12** of the second manufacturing method instance and the steps shown in **FIGS. 8 and 9** of the first manufacturing method instance.

[0105] (Fifth Manufacturing Method Instance)

[0106] In a fifth manufacturing method instance, the steps shown in **FIGS. 2 to 4** of the first manufacturing method instance are similarly used. However, in this manufacturing method instance, as shown in **FIG. 19**, a p type layer having thickness C is left over the super-junction structure of the p type layer **108** and the n type layer **106** through planarization with the CMP or the like.

[0107] As shown in **FIG. 20**, an n type impurity is added with the ion implantation or the like to a region corresponding to thickness C of **FIG. 19**. Here, a p type impurity is then added to a region of the n type impurity implanted layer over a central region of the p type layer **108**. A p type connecting region **115** is thereby formed. Subsequent steps are similar to the steps shown in **FIG. 12** of the second manufacturing method instance and the steps shown in **FIGS. 8 and 9** of the first manufacturing method instance.

[0108] (Sixth Manufacturing Method Instance)

[0109] In a sixth manufacturing method instance, the steps shown in **FIGS. 13 to 15** of the third manufacturing method instance are similarly used. As shown in **FIG. 21**, an n type layer having thickness A is then left over the super-junction structure of the p type layer **108** and the n type layer **106** through planarization with the CMP or the like. In the third manufacturing method instance, as shown in **FIG. 16**, the n type layer having thickness C instead of thickness A is left over the super-junction structure.

[0110] Subsequent steps are similar to the steps shown in **FIGS. 7 to 9** of the first manufacturing method instance.

[0111] (Seventh Manufacturing Method Instance)

[0112] In a seventh manufacturing method instance, the steps shown in **FIGS. 2 to 4** of the first manufacturing method instance are similarly used. However, in this manufacturing method instance, super-junction structure of the p type layer **108** and the n type layer **106** is formed, as shown in **FIG. 22**, for being thicker by thickness A than that of **FIG. 5**. In addition to this, in the fourth manufacturing method instance, the super-junction structure is formed for being thicker by thickness C instead of A than that of **FIG. 5**, as shown in **FIG. 17**.

[0113] As shown in **FIG. 23**, an n type impurity is added with the ion implantation or the like to a region corresponding to thickness A of **FIG. 22**. Subsequent steps are similar to the steps shown in **FIGS. 7 to 9** of the first manufacturing method instance.

[0114] (Eighth Manufacturing Method Instance)

[0115] In an eighth manufacturing method instance, the steps shown in **FIGS. 2 to 4** of the first manufacturing method instance are similarly used. However, in this manufacturing method instance, a p type layer having thickness A is formed over the super-junction structure of the p type layer **108** and the n type layer **106** through planarization with the CMP or the like, as shown in **FIG. 24**. Incidentally, in the fifth manufacturing method instance, the p type layer having thickness C instead of A is left over the super-junction structure as shown in **FIG. 19**.

[0116] As shown in **FIG. 25**, the ion implantation is repeatedly executed for forming an n type upper silicon region **110**, a p type connecting region **115**, and a p type

layer 112. In detail, for instance, an n type impurity is once added with the ion plantation to an overall region corresponding to thickness A in **FIG. 25**. Thereafter, a p type impurity is added with the ion plantation to a predetermined region corresponding to thickness C over a central region of the p type layer 108. A p type connecting region 115 is thereby formed. Furthermore, a p type impurity is added with the ion plantation to an overall region corresponding to thickness B. Subsequent steps are similar to the steps shown in **FIGS. 8 and 9** of the first manufacturing method instance.

[0117] Here, steps of the ion plantation are not limited to the above steps. An n type impurity can be, from the first step, added to a region corresponding to 110 in **FIG. 25**.

[0118] (Ninth Manufacturing Method Instance)

[0119] In a ninth manufacturing method instance, as shown in **FIG. 26**, a p type layer 108 is deposited with the epitaxial growth or the like over an n<sup>+</sup> type substrate (n<sup>+</sup> type drain region) 102. A first trench 108b is formed in a region corresponding to thickness C in **FIG. 26** through masking of the resist with the anisotropic etching (RIE or the like) or the like. As shown in **FIG. 27**, a second trench 108c having a narrower width than the first trench 108b is downwardly formed from a bottom of the first trench 108b. It is also formed for penetrating the p type layer 108 to reach the n<sup>+</sup> type drain region 102 through masking of the resist with the anisotropic etching (RIE or the like) or the like.

[0120] As shown in **FIG. 28**, an n type layer 106 is deposited in the second trench 108c and then in the first trench 108b. Thereafter, the steps shown in **FIG. 12** of the second manufacturing method instance is used and then the steps shown in **FIGS. 8 and 9** of the first manufacturing method instance are used.

[0121] In the above manufacturing method instances, concentration of the impurity can be the same or different between the n type drift region 106 and the n type upper silicon region 110. In particular, impurity concentration of the n type upper silicon region 110 can be attained to be lower than that of the drift region 106 without any additional manufacturing steps in a case where the n type drift region 106 and the n type upper silicon region 110 are not deposited consecutively. The case corresponds to the followings: the first manufacturing method instance shown in **FIG. 6**; the second manufacturing method instance shown in **FIG. 10**; the fourth manufacturing method instance shown in **FIG. 18**; the fifth manufacturing method instance shown in **FIG. 20**; the seventh manufacturing method instance shown in **FIG. 23**; and the eighth manufacturing method instance shown in **FIG. 25**.

[0122] (Second Embodiment)

[0123] A vertical semiconductor device 200 as a second embodiment is shown in a sectional view in **FIG. 29**. The vertical semiconductor device 200 includes an n<sup>-</sup> type upper silicon region 210 independently from an n type drift region 206. The n<sup>-</sup> type upper silicon region 210 has an n type impurity of 1 E 16 cm<sup>-3</sup>, while the n type drift region 206 has an n type impurity of 2.8 E 16 cm<sup>-3</sup>. It is thus favorable that the n<sup>-</sup> type upper silicon region 210 has lower impurity concentration than the n type drift region 206. With an object that the n<sup>-</sup> type upper silicon region 210 should be occupied with the depletion layer during withstanding voltage, it is favorable that the n<sup>-</sup> type upper silicon region 210 has lower

impurity concentration. By contrast, the n type drift region 206 is required to have low ON resistance in addition of high withstanding voltage, so that it favorably has high impurity concentration. The n<sup>-</sup> type upper silicon region 210 is assembled inside the p type body region 212. These are main different features from the first embodiment.

[0124] Simulation result of a characteristic of the vertical semiconductor device 200 will be explained below. A characteristic of drain voltage V<sub>D</sub> and drain electric current ID (withstanding-voltage characteristic) of the semiconductor device 200 is shown in **FIG. 30**. The drain voltage V<sub>D</sub> is increased every 0.2 V in a range from 0 to 250 V. Here, gate voltage, source voltage, and body voltage are set to 0 V. At about 240 V of the drain voltage V<sub>D</sub>, the semiconductor device 200 is broken down. This means that break-down voltage is about 240 V.

[0125] Voltage distribution of the semiconductor device 200 is shown at 200 V of the drain voltage V<sub>D</sub> in **FIG. 31**. **FIG. 31** shows a half cell of the semiconductor device 200 corresponding to width B region in **FIG. 29** with depletion layer edges. It is shown that the n type drift region 206, p type silicon region 208, and n<sup>-</sup> type silicon region 210 are thoroughly occupied with the depletion layers. Electric potential contour lines are distributed at almost even intervals.

[0126] A characteristic of gate voltage V<sub>G</sub> and drain electric current I<sub>D</sub> (ON characteristic) of the semiconductor device 200 is shown in **FIG. 32**. The gate voltage V<sub>G</sub> is increased every 0.05 V in a range from 0 to 20 V. Here, the drain voltage V<sub>D</sub> is set to 0.1 V. The source voltage and the body voltage are set to 0 V. From **FIG. 32**, at V<sub>G</sub>=15 V the ON resistance (R<sub>ON</sub>) of the semiconductor device 200 is calculated to be about 0.17 Ω mm<sup>2</sup>.

[0127] Electric current flow of the semiconductor device 200 is shown at 15 V of the gate voltage V<sub>G</sub> in **FIG. 33**. **FIG. 33** also shows the half cell of the semiconductor device 200 corresponding to width B region in **FIG. 29**. It is shown that a channel is formed not in a p type silicon region 208, but only in a region 212a inside a p type body region 212 close to a side wall of a gate trench 213.

[0128] A characteristic of break-down voltage V<sub>B</sub> and ON resistance R<sub>ON</sub> of the semiconductor device 200 is shown in **FIG. 34**. A curve shown in **FIG. 34** shows a silicon limit. The silicon limit is a minimum value of the ON resistance uniquely determined by withstanding voltage as described in "POWER MOSFETS Theory and Applications" (author: D. A. Grant, publisher: John Wiley & Sons). It is shown that the ON resistance R<sub>ON</sub> is increased with increasing break-down voltage V<sub>B</sub>.

[0129] Point A in **FIG. 34** is plotted based on break-down voltage V<sub>B</sub> (about 240 V) and ON resistance R<sub>ON</sub> (about 0.17 Ω mm<sup>2</sup>) derived from **FIGS. 30 and 32**. In the silicon limit, at break-down voltage V<sub>B</sub>=240 V, ON resistance R<sub>ON</sub> measures about 0.54 Ω mm<sup>2</sup>. Namely, the ON resistance R<sub>ON</sub> of the semiconductor device 200 is less than one third of the ON resistance along the silicon limit curve. The structure of the semiconductor device 200 of the second embodiment provides a semiconductor device simultaneously having high withstanding voltage and low ON resistance. This performance is superior to that corresponding to the silicon limit.

[0130] (Third Embodiment)

[0131] A vertical semiconductor device 300 as a third embodiment is shown in a sectional view in FIG. 35. In the vertical semiconductor device 300, width (0.5  $\mu\text{m}$ ) of an n type drift region 306 is narrower than width (1  $\mu\text{m}$ ) of the n type drift region 106 of the first embodiment shown in FIG. 1. The n type drift region 306 has an n type impurity of 6.5 E 16  $\text{cm}^{-3}$ . Width (3.5  $\mu\text{m}$ ) of a p type silicon region 308 is broader than width (3  $\mu\text{m}$ ) of the p type silicon region 108 of the first embodiment. The p type silicon region 308 has a p type impurity of 1.0 E 16  $\text{cm}^{-3}$ . Width (0.7  $\mu\text{m}$ ) of an n type upper silicon region 310 is narrower than width (3  $\mu\text{m}$ ) of the n type upper silicon region 110 of the first embodiment. Here, the n type upper silicon region 310 and the n type drift region 308 are formed as one uniform body with having a boundary at dotted line Y in FIG. 35.

[0132] Width (0.7  $\mu\text{m}$ ) of the n type upper silicon region 310 is narrower than that (1.2  $\mu\text{m}$ ) of a gate trench 313. The n type upper silicon region 310 connects with the n type drift region 306, while it does not connect with a p type body region 312. Thickness (0.3  $\mu\text{m}$ ) of the n type upper silicon region 310 is thinner than that (1  $\mu\text{m}$ ) of the n type upper silicon region 110 of the first embodiment. The n type upper silicon region 310 is disposed only under a bottom of the gate trench 313, while the n type upper silicon region 110 of the first embodiment surrounds the lower side walls and bottom of the gate trench 113. The n type upper silicon region 310 has an n type impurity of 6.5 E 16  $\text{cm}^{-3}$ . These are different features from the first embodiment.

[0133] In the vertical semiconductor device 300 of the third embodiment, the n type upper silicon region 310 has narrow width and thin thickness. When horizontal misalignment of masking or vertical misalignment of depth control is small, the ON resistance can be prevented from increasing by lessening a region where a channel is formed inside the p type silicon region.

[0134] (Fourth Embodiment)

[0135] A vertical semiconductor device 400 as a fourth embodiment is shown in a sectional view in FIG. 36. In the vertical semiconductor device 400, relationship between alternate layers of super-junction structure 404 and a gate electrode 420 (or gate trench 413) is different from that of the first embodiment. In detail, an n type drift region 406 is not disposed under the gate trench 413, but under a region that is located between the gate trenches 413. The n type drift region 406 has width of 0.8  $\mu\text{m}$  and an n type impurity of 3.7 E 16  $\text{cm}^{-3}$ . Under the gate trench 413, a p type silicon region 408 is disposed. The p type silicon region 408 has width of 3.2  $\mu\text{m}$  and a p type impurity of 1.0 E 16  $\text{cm}^{-3}$ .

[0136] An n type upper silicon region 410 is disposed near a lower side wall of the gate trench 413 in an uppermost portion of the p type silicon region 408. The n type upper silicon region 410 has width of 0.8  $\mu\text{m}$  and thickness of 1  $\mu\text{m}$  with an n type impurity of 3.7 E 16  $\text{cm}^{-3}$ . The n type upper silicon region 410 connects with a p type body region 412, but does not connect with the gate trench 413 (gate insulation film 418). The p type silicon region 408 has, between the gate trench 413 and the n type upper silicon region 410, a small portion 408a that is 0.2  $\mu\text{m}$  wide and connects with the p type body region 412.

[0137] In the vertical semiconductor device 400 of the fourth embodiment, an electron inside the p type body

region 412 congregates in a region 412a while the semiconductor device 400 is in an ON state. An n type channel is thereby formed in the region 412a similarly with the first embodiment. An electron supplied from an n<sup>+</sup> type source region 414 flows through the n type channel 412a, the n type upper silicon region 410, and the n type drift region 406 to reach an n<sup>+</sup> type drain region 402. Here, when the electron reaches the n type upper silicon region 410 from the n type channel 412a, it passes slightly through a region 408a inside the p type silicon region 408. An n type channel is thereby formed inside the p type silicon region 408. However, the formed n type channel is much lessened in comparison with that of a semiconductor device having no n<sup>+</sup> type upper silicon region.

[0138] During withstanding voltage, depletion layers are broadened from pn conjunctions 407, 409 towards regions 406, 408, and 410. The regions 406, 408 are thereby completely occupied with the depletion layers, which phenomena leads to obtaining high withstanding voltage.

[0139] (Fifth Embodiment)

[0140] A vertical semiconductor device 500 as a fifth embodiment is shown in a sectional view in FIG. 37. In the vertical semiconductor device 500, no upper silicon layer is provided, but an n type drift region 506 connects with a p type body region 512. The n type drift region 506 also connects with a region 512a where an n type channel is formed. A p type silicon region 508 connects with the p type body region 512. Width (1.4  $\mu\text{m}$ ) of the n type drift region 506 is broader than that (0.7  $\mu\text{m}$ ) of a gate trench 513 by almost same length in each of both ends of the width. The n type drift region 506 surrounds lower side walls 513a and a bottom of the gate trench 513. The n type drift region 506 has an n type impurity of 2.0 E 16  $\text{cm}^{-3}$ . Width (1.4  $\mu\text{m}$ ) of the p type silicon region 508 is narrower than that (3.0  $\mu\text{m}$ ) of the p type silicon region 108 of the first embodiment. The p type silicon region 508 has an p type impurity of 2.0 E 16  $\text{cm}^{-3}$ . These are different features from the first embodiment.

[0141] Structure of the vertical semiconductor device 500 of the fifth embodiment prevents ON resistance due to masking or depth control misalignment from increasing even without the upper silicon region. Here, the p type silicon region 508 is not shifted into floating electric potential, so that a withstanding-voltage characteristic is maintained to be stable. Furthermore, an electric current passage is shortened between the p type silicon region 508 and the p type body region 512.

[0142] Here, width of the n type drift region 506 must be broader than that of the gate trench 513. It is difficult for the width of a trench to be less than 0.5  $\mu\text{m}$  at present technology. Even if masking misalignment occurs, the bottom of the gate trench 513 must be thoroughly inside the n type drift region 506. Width Z shown in FIG. 37 is therefore set to 0.35  $\mu\text{m}$ . The n type drift region 506 thereby requires width of 1.4  $\mu\text{m}$ .

[0143] Simulation result of a characteristic of the vertical semiconductor device 500 will be explained below. Here, the n type drift region 506 and the p type silicon region similarly have width of 1.4  $\mu\text{m}$  and impurity concentration of 2 E 16  $\text{cm}^{-3}$ . A characteristic of withstanding voltage is shown in FIG. 38. Here, conditions regarding drain voltage or the like are same as that of the second embodiment (FIG. 30). It is shown that breakdown voltage is about 238 V.

[0144] Voltage distribution of the semiconductor device **500** is shown at 200 V of the drain voltage  $V_D$  in **FIG. 39**. It is shown that the n type drift region **506** and p type silicon region **508** are thoroughly occupied with depletion layers. Electric potential contour lines are distributed at almost even intervals.

[0145] An ON characteristic of the semiconductor device **500** is shown in **FIG. 40**. Here, conditions regarding gate voltage or the like are same as that of the second embodiment (**FIG. 32**). From **FIG. 40**, at  $V_G=15$  V the ON resistance ( $R_{ON}$ ) of the semiconductor device **500** is calculated to be about  $0.09 \Omega \text{ mm}^2$ . This performance of the fifth embodiment is also much superior to that corresponding to the silicon limit.

[0146] Electric current flow of the semiconductor device **500** is shown at 15 V of the gate voltage  $V_G$  in **FIG. 41**. It is shown that a channel is formed not in the p type silicon region **508**, but only in a region **512a** inside the p type body region **512** close to the side wall of the gate trench **513**.

[0147] (Other Modifications)

[0148] The above embodiments are explained regarding the n type power MOS. However, the present invention can be directed to a p type power MOS. Furthermore, the present invention can be directed to not only the U-shaped MOS, but also V-shaped MOS, IGBT, MOS gate thyristor, or the like.

[0149] Although the first to ninth manufacturing method instances are explained regarding the first embodiment, similar manufacturing method instances are adopted for the second to fifth embodiments. Technologies included in the first to ninth manufacturing method instances are directed to the second to fifth embodiments.

What is claimed is:

1. A semiconductor device comprising:
  - a drain region that is a first-conductivity type;
  - a drift region that is a first-conductivity type and connects with the drain region;
  - a body region that is a second-conductivity type;
  - a source region that is a first-conductivity type and connects with the body region;
  - a gate electrode that is provided, with being covered by a gate insulation film, in a gate trench that penetrates the body region;
  - a first semiconductor region that is a first-conductivity type and provided between the drift region and the body region; and
  - a second semiconductor region that is a second-conductivity type and connects with the drift region and the body region.
2. A semiconductor device according to claim 1, wherein, when electric voltage is applied to the gate electrode, a channel is formed inside the body region, wherein carriers flow from the source region to the drain region through the channel and the drift region, and wherein the first semiconductor region is located at least in a portion of a region where the carriers flow through.
3. A semiconductor device according to claim 1, wherein the first semiconductor region connects with at least one of the drift region and the body region.
4. A semiconductor device according to claim 3, wherein, when electric voltage is applied to the gate electrode, a channel is formed in the body region, and wherein the first semiconductor region connects with the channel.
5. A semiconductor device according to claim 1, wherein the drift region is provided below the gate trench, wherein the first semiconductor region is provided between the drift region and a bottom of the gate trench, and wherein the first semiconductor region has, in a width direction of the gate trench, broader width than the drift region.
6. A semiconductor device according to claim 5, wherein the first semiconductor region has the broader width than the drift region by almost same length in each of both ends of the width.
7. A semiconductor device according to claim 1, wherein the drift region is provided below the gate trench, wherein the first semiconductor region is provided between the drift region and a bottom of the gate trench, and wherein the first semiconductor region has, in a width direction of the gate trench, broader width than the gate trench.
8. A semiconductor device according to claim 7, wherein the first semiconductor region has the broader width than the gate trench by almost same length in each of both ends of the width.
9. A semiconductor device according to claim 1, wherein the first semiconductor region surrounds a bottom of the gate trench and lower portions of side walls of the gate trench.
10. A semiconductor device comprising:
  - a drain region that is a first-conductivity type;
  - a drift region that is a first-conductivity type and connects with the drain region;
  - a body region that is a second-conductivity type and connects with the drift region;
  - a source region that is a first-conductivity type and connects with the body region;
  - a gate electrode that is provided, with being covered by a gate insulation film, in a gate trench that penetrates the body region; and
  - a semiconductor region that is a second-conductivity type and connects with the drift region and the body region.
11. A semiconductor device according to claim 10, wherein, when electric voltage is applied to the gate electrode, a channel is formed inside the body region, and wherein the drift region connects with the channel.

**12.** A semiconductor device according to claim 10, wherein the drift region is provided below the gate trench, and wherein the drift region has, in a width direction of the gate trench, broader width than the gate trench.

**13.** A semiconductor device according to claim 12, wherein the drift region has the broader width than the gate trench by almost same length in each of both ends of the width.

**14.** A semiconductor device according to claim 10, wherein the drift region surrounds a bottom of the gate trench and lower portions of side walls of the gate trench.

**15.** A semiconductor device manufacturing method comprising steps of:

- forming a drain region of a first-conductivity type;
- forming, over a surface of the drain region, alternate layers of a drift region of a first-conductivity type and a second semiconductor region of a second-conductivity type, wherein the alternate layers are substantially orthogonal to the surface of the drain region;
- forming, over the drift region, a first semiconductor region of a first-conductivity type, wherein the first semiconductor region is broader than the drift region in a direction parallel with the surface of the drain region;
- forming, over the second semiconductor region and the first semiconductor region, a body region of a second-conductivity type;
- forming a gate trench that penetrates the body region and connects with the first semiconductor region; and
- filling a gate electrode in the gate trench.

**16.** A semiconductor device manufacturing method according to claim 15, wherein the first semiconductor region is formed for being broader than the gate trench in the direction parallel with the surface of the drain region.

**17.** A semiconductor device manufacturing method according to claim 15, wherein, after the alternate layers of the drift region and the second semiconductor region are formed, an intermediate first semiconductor region of the first-semiconductor type is formed, wherein a connecting region that is a second-conductivity type and reaches the second semiconductor region is then formed as an extended portion of the second semiconductor region by adding a second-conductivity-type impurity to a portion of the intermediate first semiconductor region, and the first semiconductor region is formed as a region excluding the connecting region from the intermediate first semiconductor region, and wherein the body region is formed for being deposited over the first semiconductor region and the second semiconductor region that includes the connecting region.

**18.** A semiconductor device manufacturing method according to claim 15, wherein, after the alternate layers of the drift region and the second semiconductor region are formed, an intermediate first semiconductor region of the first-semiconductor type is formed, wherein a certain trench that penetrates a portion of the intermediate first semiconductor region to reach the second semiconductor region is formed, and the first semiconductor region is formed as a region excluding a region of the certain trench from the intermediate first semiconductor region, and wherein the body region is formed for being deposited over the first semiconductor region and inside the certain trench over the second semiconductor region.

**19.** A semiconductor device manufacturing method according to claim 18, wherein the intermediate first semiconductor region is formed for being deposited over the alternate layers of the drift region and the second semiconductor region.

**20.** A semiconductor device manufacturing method according to claim 19, wherein, after the drain region is formed, an intermediate second semiconductor region of a second-conductivity type is deposited over the drain region, wherein a given trench is formed for penetrating a portion of the intermediate second semiconductor region to reach the drain region, wherein the alternate layers of the drift region and the second semiconductor region are formed by depositing the drift region inside the given trench, and wherein the intermediate first semiconductor region is then consecutively formed for being deposited.

**21.** A semiconductor device manufacturing method according to claim 15, wherein, after the alternate layers of the drift region and the second semiconductor region are formed, an intermediate second-conductivity-type layer is formed for being deposited over the alternate layers, and wherein the first semiconductor region is formed by adding a first-conductivity type impurity to the intermediate second-conductivity-type layer.

**22.** A semiconductor device manufacturing method according to claim 15, wherein, after the alternate layers of the drift region and the second semiconductor region are formed, the first semiconductor region is formed by adding a first-conductivity-type impurity to upper portions of the alternate layers.

**23.** A semiconductor device manufacturing method according to claim 15, wherein, after the drain region is formed, an intermediate drift region of a first-conductivity type is formed over the drain region, wherein a given trench is formed for penetrating a portion of the intermediate drift region to reach the drain region, wherein the alternate layers of the drift region and the second semiconductor region are formed by depositing the second semiconductor region inside the given trench,

wherein an intermediate second-conductivity-type layer is then consecutively formed for being deposited, and

wherein the first semiconductor region is then formed by adding a first-conductivity-type impurity to the intermediate second-conductivity-type layer.

**24.** A semiconductor device manufacturing method according to claim 15,

wherein, after the drain region is formed, an intermediate second semiconductor region of a second-conductivity type is deposited over the drain region,

wherein a given trench is formed for penetrating a portion of the intermediate second semiconductor region to reach the drain region,

wherein the alternate layers of the drift region and the second semiconductor region are formed by depositing the drift region inside the given trench,

wherein the intermediate first semiconductor region is then consecutively formed for being deposited,

wherein the first semiconductor region is formed, along with a connecting region that is a second-conductivity type and connects with the second semiconductor region, at least by adding a second-conductivity-type impurity to a certain portion of the intermediate first semiconductor region, and

wherein the body region is also formed at least by adding the second-conductivity-type impurity to a given portion of the intermediate first semiconductor region.

**25.** A semiconductor device manufacturing method according to claim 15,

wherein, after the alternate layers of the drift region and the second semiconductor region are formed, an intermediate first-conductivity-type layer is formed by adding a first-conductivity-type impurity to upper portions of the alternate layers, and

wherein the first semiconductor region and the body region are formed, along with a second-conductivity-type connecting region that is formed as one of an extended portion of the second semiconductor region and an extended portion of the body region, at least by adding a second-conductivity-type impurity to the intermediate first-conductivity-type layer.

**26.** A semiconductor device manufacturing method according to claim 15,

wherein, after the drain region is formed, an intermediate drift region of a first-conductivity type is formed over the drain region,

wherein a given trench is formed for penetrating a portion of the intermediate drift region to reach the drain region,

wherein the alternate layers of the drift region and the second semiconductor region are formed by depositing the second semiconductor region inside the given trench,

wherein an intermediate second-conductivity-type layer is then consecutively formed for being deposited, and

wherein the first semiconductor region is then formed, along with the body region and a second-conductivity-type connecting region that is formed as one of an extended portion of the second semiconductor region and an extended portion of the body region, at least by adding a first-conductivity-type impurity to a portion of the intermediate second-conductivity-type layer.

**27.** A semiconductor device manufacturing method according to claim 15,

wherein, after the drain region is formed, an intermediate second semiconductor region is formed over the drift region, a certain trench is formed over the intermediate second semiconductor region, and a given trench is formed under the certain trench with adjoining a bottom of the certain trench for penetrating the intermediate second semiconductor region to reach the drain region, wherein the given trench is narrower in width than the certain trench, and

wherein the drift region is formed for being deposited inside the given trench and, then consecutively, the first semiconductor region is formed for being deposited inside the certain trench.

**28.** A semiconductor device including:

a drain region that is a first-conductivity type;

a drift region that is a first-conductivity type and connects with the drain region;

a body region that is a second-conductivity type;

a source region that is a first-conductivity type and connects with the body region; and

a gate electrode that is provided, with being covered by a gate insulation film, in a gate trench that penetrates the body region,

wherein a channel is formed inside the body region when electric voltage is applied to the gate electrode, and

wherein carriers flow from the source region through the body region and the drift region to the drain region,

the semiconductor device comprising:

a first semiconductor region that is a first-conductivity type and provided at least in a portion of a carrier passage that interordinates between the drift region and the body region; and

a second semiconductor region that is a second-conductivity type and connects with the drift region and the body region.