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Semiconductor device

Abstract

In an IGBT region of a semiconductor device, a barrier region is disposed above a drift layer, and a contact trench is disposed between adjacent gate trenches in a semiconductor substrate. A first electrode is embedded in the contact trench. A connecting region is disposed between a bottom surface of the contact trench and the barrier region, and is connected to the barrier region and the first electrode. Further, the emitter region and the contact region are arranged in a direction different from an arrangement direction of the gate trenches. Thus, the semiconductor device can be miniaturized.

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATION

(1) The present application claims the benefit of priority from Japanese Patent Application No. 2021-049874 filed on Mar. 24, 2021. The entire disclosures of the above application are incorporated herein by reference.

TECHNICAL FIELD

(2) The present disclosure relates to a semiconductor device in which an insulated gate bipolar transistor (hereinafter referred to as an IGBT) element having an insulated gate structure and a free wheel diode (hereinafter referred to as FWD) element are formed on a common semiconductor substrate.

BACKGROUND

(3) As a switching element used in an inverter or the like, for example, there is a semiconductor device in which an IGBT region having an IGBT element and an FWD region having an FWD element are formed on a common semiconductor substrate.

SUMMARY

(4) The present disclosure describes a semiconductor device in which an IGBT region having an IGBT element and an FWD region having an FWD element are formed on a common semiconductor substrate. In the IGBT region of the semiconductor device, a barrier region is disposed above a drift layer, and a contact trench is disposed between adjacent gate trenches in a semiconductor substrate. A first electrode is embedded in the contact trench. A connecting region is disposed between a bottom surface of the contact trench and the barrier region, and is connected to the barrier region and the first electrode. Further, the emitter region and the contact region are arranged in a direction different from an arrangement direction of the gate trenches. Thus, the semiconductor device can be miniaturized.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

- (1) Objects, features and advantages of the present disclosure will become more apparent from the following detailed description made with reference to the accompanying drawings, in which:
- (2) FIG. 1 is a plan view of a semiconductor device according to a first embodiment of the present disclosure;
- (3) FIG. 2 is a cross-sectional view of the semiconductor device taken along a line II-II shown in FIG. 1;
- (4) FIG. 3 is a cross-sectional view of a semiconductor device according to a second embodiment of the present disclosure;
- (5) FIG. 4 is a cross-sectional view of a semiconductor device according to a modification of the second embodiment;
- (6) FIG. 5 is a cross-sectional view of a semiconductor device according to a third embodiment of the present disclosure;
- (7) FIG. 6 is a cross-sectional view of a part of the semiconductor device according to the third embodiment, which is different from a part shown in FIG. 5;
- (8) FIG. 7 is a cross-sectional view of a semiconductor device according to a fourth embodiment of the present disclosure;
- (9) FIG. 8 is a cross-sectional view of a part of the semiconductor device according to the fourth embodiment, which is different from a part shown in FIG. 7;
- (10) FIG. 9 is a cross-sectional view of a semiconductor device according to a fifth embodiment of the present disclosure;
- (11) FIG. 10 is a cross-sectional view of a semiconductor device according to a sixth embodiment of the present disclosure;
- (12) FIG. 11 is a cross-sectional view of a part of the semiconductor device according to the sixth embodiment, which is different from a part shown in FIG. 10;
- (13) FIG. 12 is a schematic diagram showing a part through which a current flows, when an FWD element is in an on state, in a semiconductor device according to a seventh embodiment;
- (14) FIG. 13 is a cross-sectional view of a first section of the IGBT region according to the seventh embodiment;
- (15) FIG. 14 is a cross-sectional view of an FWD region of a semiconductor device according to a modification of the seventh embodiment; and
- (16) FIG. 15 is a cross-sectional view of the FWD region of the semiconductor device according to the modification of the seventh embodiment.

DETAILED DESCRIPTION

(17) To begin with, a relevant technology will be described only for understanding the embodiments of the present disclosure.

(18) In a semiconductor device, an IGBT region having an IGBT element and an FWD region

having an FWD element are formed on a common semiconductor substrate.

(19) In such a semiconductor device, for example, a base layer is disposed adjacent to a first surface of a semiconductor substrate constituting an n.sup.- type drift layer, and a plurality of gate trenches are disposed so as to penetrate the base layer. Each of the gate trenches is extended in one direction along a planar direction of the semiconductor substrate as a longitudinal direction. In each of the gate trenches, a gate insulating film and a gate electrode are sequentially formed.

(20) Further, an n type barrier region is disposed on the drift layer along the planar direction of the semiconductor substrate. The barrier region is disposed at the interface between the drift layer and the base layer, or at a portion in the base layer adjacent to the drift layer.

(21) In a surface layer portion of the base layer, an n.sup.+ type emitter region is disposed so as to be in contact with the gate trench, and a p.sup.+ type contact region having a higher impurity concentration than the base layer is disposed. Further, an n type pillar region is disposed in the base layer so as to reach the barrier region. Specifically, the emitter region and the contact region are disposed between adjacent gate trenches in a manner that the emitter region is in contact with each gate trench, and the contact region is located opposite to the gate trench with respect to the emitter region. That is, the emitter region and the contact region are arranged in an arrangement direction of the plurality of gate trenches. The pillar region is disposed so as to penetrate the contact region and reach the barrier region.

(22) An upper electrode is disposed adjacent to the first surface of the semiconductor substrate so as to be connected to the emitter region, the contact region, and the barrier region. A p.sup.+ type collector layer and an n.sup.+ type cathode layer are disposed adjacent to a second surface of the semiconductor substrate. Further, a lower electrode is disposed on the second surface of the semiconductor substrate to be electrically connected to the collector layer and the cathode layer.

(23) In such a semiconductor device, a region in which the collector layer is disposed on the second surface of the semiconductor substrate serves as an IGBT region, and a region in which the cathode layer is disposed on the second surface of the semiconductor substrate serves as an FWD region. Since the FWD region is configured as described above, the FWD element is provided with an FWD element having a PN junction, which is formed by the n type cathode layer, the n type drift layer, and the p type base layer.

(24) In the semiconductor device described above, however, the contact region and the emitter region are arranged side by side in the arrangement direction of the gate trenches. Therefore, it is difficult to narrow the distance between adjacent gate trenches, and it is difficult to miniaturize the semiconductor device.

(25) The present disclosure provides a semiconductor device capable of miniaturization.

(26) In a semiconductor device according to an aspect of the present disclosure, a semiconductor substrate includes an IGBT region having an IGBT element and a FWD region having an FWD element. The semiconductor substrate has a first conductivity type drift layer, a second conductivity type base layer disposed on the drift layer, a second conductivity type collector layer disposed opposite to the base layer with respect to the drift layer in the IGBT region, and a first conductivity type cathode layer disposed opposite to the base layer with respect to the drift layer in the FWD region. The semiconductor substrate has a first surface adjacent to the base layer and a second surface opposite to the first surface and adjacent to the collector layer and the cathode layer. A gate insulating film is disposed on a wall surface of each of a plurality of gate trenches disposed in the semiconductor substrate in the IGBT region. In the semiconductor substrate, the plurality of gate trenches are arranged in an arrangement direction. Each of the plurality of gate trenches passes through the base layer to reach the drift layer and extends in one direction as a longitudinal direction along a planar direction of the semiconductor substrate. A gate electrode is disposed on the gate insulating film. A first conductivity type emitter region, which has a higher impurity concentration than the drift layer, is disposed in a surface layer portion of the base layer in the IGBT region to be in contact with each of the gate trenches. A second conductivity type contact

region, which has a higher impurity concentration than the base layer, is disposed in the base layer in the IGBT region. A first electrode is disposed adjacent to the first surface of the semiconductor substrate, and is electrically connected to the base layer and the emitter region. A second electrode is disposed adjacent to the second surface of the semiconductor substrate, and is electrically connected to the collector layer and the cathode layer. A first conductivity type barrier region, which has a higher impurity concentration than the drift layer, is disposed above the drift layer in the IGBT region. Further, the semiconductor substrate is formed with a contact trench between the adjacent gate trenches in the IGBT region, and the contact trench has a bottom surface adjacent to the first surface of the semiconductor substrate than the barrier region. The first electrode is embedded in the contact trench. In addition, a first conductivity type connecting region is disposed between the bottom surface of the contact trench and the barrier region in the IGBT region. The connecting region has a higher impurity concentration than the drift layer, and is connected to the barrier region and the first electrode. The emitter region and the contact region are arranged in a direction different from the arrangement direction of the gate trenches.

(27) In such a configuration, the emitter region and the contact region are arranged in a direction different from the arrangement direction of the gate trenches. Therefore, the distance between the adjacent gate trenches can be easily narrowed, as compared with the configuration in which the emitter region and the contact region are arranged in the arrangement direction of the gate trenches. Accordingly, miniaturization of the semiconductor device can be achieved.

(28) Hereinafter, embodiments of the present disclosure will be described with reference to the drawings. In the embodiments described hereinafter, the same or equivalent parts are designated with the same reference numerals.

First Embodiment

(29) A first embodiment will be described with reference to the drawings. For example, a semiconductor device according to the present embodiment is suitably used as a power switching element used in power supply circuits such as inverters or DC/DC converters.

(30) As shown in FIG. 1, the semiconductor device includes cell regions **1** and an outer peripheral region **2** surrounding the cell regions **1**. In the present embodiment, the semiconductor device has two cell regions **1**. Each of the cell regions **1** is provided with an IGBT region **1a** that functions as an IGBT element and an FWD region **1b** that functions as an FWD element. That is, the semiconductor device of the present embodiment is a reverse conducting insulated gate bipolar transistor (RC-IGBT) in which an IGBT region **1a** and an FWD region **1b** are formed in the same chip.

(31) In the present embodiment, the IGBT regions **1a** and the FWD regions **1b** are alternately arranged in one direction in each of the cell regions **1**. That is, the IGBT regions **1a** and the FWD regions **1b** are alternately arranged in one direction, the one direction being included in the plane of the semiconductor substrate **10** as will be described later. Specifically, each of the IGBT region **1a** and the FWD region **1b** is a rectangular region having a longitudinal direction, and the IGBT regions **1a** and the FWD regions **1b** are alternately arranged in the one direction as an arrangement direction so that the longitudinal direction of each of the IGBT regions **1a** and the FWD regions **1b** intersects with the arrangement direction. Further, the IGBT regions **1a** and the FWD regions **1b** are alternately arranged so that the IGBT regions **1a** are located at both ends in the arrangement direction.

(32) As shown in FIG. 1, the IGBT regions **1a** and the FWD regions **1b** each have the rectangular shape defining the longitudinal direction in a left and right direction of FIG. 1, and are arranged alternately in an up and down direction in FIG. 1 as the arrangement direction. Further, as will be described in detail later, in the present embodiment, the IGBT region **1a** is a region provided above a collector layer **25**, and the FWD region **1b** is a region provided above a cathode layer **26**.

(33) As shown in FIG. 2, the semiconductor device includes a semiconductor substrate **10** having an n.sup.- type drift layer **11**. The semiconductor substrate **10** is made of a silicon substrate. The

semiconductor substrate has a p type base layer **12** above the drift layer **11**. In the following description, the surface of the semiconductor substrate **10** on the base layer **12** side will be referred to as a first surface **10a** of the semiconductor substrate **10**, and the surface of the semiconductor substrate **10** opposite to the first surface **10a** and on the drift layer **11** side will be referred to as a second surface **10b** of the semiconductor substrate **10**. In the semiconductor device of the present embodiment, the IGBT region **1a** and the FWD region **1b** have the same configuration on the first surface **10a** side of the semiconductor substrate **10**.

(34) An n.sup.+ type barrier region **13** having a higher impurity concentration than the drift layer **11** is disposed in a portion of the base layer **12** adjacent to the drift layer **11**. In the present embodiment, the barrier region **13** is disposed entirely along the planar direction of the semiconductor substrate **10**. In the following description, the barrier region **13** is exemplarily formed in the portion of the base layer **12** adjacent to the drift layer **11**. As another example, the barrier region **13** may be formed at the interface between the drift layer **11** and the base layer **12**.

(35) A plurality of gate trenches **14** are formed in the semiconductor substrate **10** so as to extend in a depth direction from the first surface **10a** and reach the drift layer **11** while passing through the base layer **12** and the barrier region **13**. As a result, the base layer **12** and the barrier region **13** are separated into plural parts by the gate trenches **14**. In the present embodiment, the plurality of gate trenches **14** are disposed in the IGBT region **1a** and the FWD region **1b**, respectively. Further, the plurality of gate trenches **14** are formed in a striped shape. Each of the gate trenches **14** has a longitudinal direction in one direction intersecting the arrangement direction of the IGBT regions **1a** and the FWD regions **1b**. That is, each gate trench **14** has a striped shape extending in a direction normal to the paper surface of FIG. 2 as the longitudinal direction.

(36) Each gate trench **14** is filled with a gate insulating film **15** and a gate electrode **16**. The gate insulating film **15** is disposed so as to cover the wall surface of the gate trench **14**. The gate electrode **16** is made of polysilicon or the like, and is embedded on the gate insulating film **15** in the gate trench **14**. In this way, a trench gate structure is formed.

(37) Further, a contact trench **17** is formed between the adjacent gate trenches **14** in the semiconductor substrate **10**. The contact trench **17** is formed on the first surface **10a** side of the semiconductor substrate **10**. In the present embodiment, the contact trench **17** is extended in the longitudinal direction of the gate trench **14**. The contact trench **17** is disposed shallower than the gate trench **14** and is disposed so as not to reach the barrier region **13**. That is, the contact trench **17** is disposed so as not to expose the barrier region **13** from its bottom surface.

(38) In the surface layer portion of the base layer **12**, an n.sup.++ type emitter region **18** and a p.sup.+ type contact region **19** are formed. The n.sup.++ type emitter region **18** has a higher impurity concentration than the drift layer **11** and the barrier region **13**, and the p.sup.+ type contact region **19** has a higher impurity concentration than the base layer **12**. In the present embodiment, the emitter region **18** is extended in the longitudinal direction of the gate trench **14**, and is exposed from the first surface **10a** of the semiconductor substrate **10**. The emitter region **18** is disposed so as to be in contact with the side surface of the gate trench **14** and the side surface of the contact trench **17**. In addition, the emitter region **18** is disposed so as to be terminated within the base layer **12**. The contact region **19** is disposed between the emitter region **18** and the barrier region **13**, and is in contact with the side surface of the contact trench **17**. In the present embodiment, therefore, the emitter region **18** and the contact region **19** are arranged in a thickness direction of the semiconductor substrate **10**. Note that the contact region **19** of the present embodiment is not formed below a portion of the emitter region **18**, the portion being in contact with the gate trench **14**. That is, a portion of the base layer **12** is arranged between the side surface of the gate trench **14** and the contact region **19**. A portion of the base layer **12** being in contact with the side surface of the gate trench **14** serves as a region constituting a channel region.

(39) An n.sup.+ type connecting region **20** having a higher impurity concentration than the drift layer **11** is disposed between the bottom surface of the contact trench **17** and the barrier region **13**.

Specifically, the connecting region **20** is disposed so as to connect between the bottom surface of the contact trench **17** and the barrier region **13**.

(40) The contact region **19** and the connecting region **20** of the present embodiment are formed as follows. For example, after the contact trench **17** is formed, the contact region **19** is formed to be in contact with a side surface of the contact trench **17**. In this case, the contact region **19** is formed, for example, by implanting ions in an oblique direction inclined relative to a normal direction to the first surface **10a** of the semiconductor substrate **10**. The connecting region **20** is formed, for example, by implanting ions into the bottom surface of the contact trench **17**, after the contact trench **17** is formed.

(41) An interlayer insulating film **21** is disposed on the first surface **10a** of the semiconductor substrate **10**. The interlayer insulation film **21** is made of borophosphosilicate glass (BPSG) or the like. The interlayer insulating film **21** is formed with a contact hole **21a** communicating with the contact trench **17** formed in the semiconductor substrate **10**. Hereinafter, the contact trench **17** and the contact hole **21a** are collectively referred to as a connection trench **22**. The contact hole **21a** of the present embodiment has a shape corresponding to the contact trench **17**, and is extended in the longitudinal direction of the gate trench **14**, similarly to the contact trench **17**. Therefore, the connection trench **22** of the present embodiment is in a state of being extended in the longitudinal direction of the gate trench **14**.

(42) An upper electrode **23** is formed on the interlayer insulating film **21**. The upper electrode **23** is electrically connected to the emitter region **18**, the contact region **19**, and the connecting region **20** through the connection trench **22**. In the present embodiment, the upper electrode **23** has a connection electrode **230** that is embedded in the connection trench **22** and a main electrode **231** that is arranged on the interlayer insulating film **21** and connected to the connection electrode **230**.

(43) The connection electrode **230** of the present embodiment includes a barrier metal portion **230a** and an embedded portion **230b**. The barrier metal portion **230a** is made of Ti/TiN or the like, and is formed along the wall surface of the contact trench **17**. The embedded portion **230b** is made of a tungsten plug or the like, and is formed on the barrier metal portion **230a**. The main electrode **231** is made of aluminum or the like.

(44) The upper electrode **23** is electrically connected to the emitter region **18** and the contact region **19** in a state of ohmic contact. Further, the upper electrode **23** is electrically connected to the connecting region **20** in a state of Schottky barrier junction. The upper electrode **23** functions as an emitter electrode in the IGBT region **1a** and functions as an anode electrode in the FWD region **1b**. In the present embodiment, the upper electrode **23** corresponds to a first electrode.

(45) An n type field stop layer (hereinafter referred to as an FS layer) **24** having a higher impurity concentration than the drift layer **11** is disposed in a portion of the drift layer **11** on the opposite side to the base layer **12** with respect to the drift layer **11**. That is, the FS layer **24** is disposed on a side adjacent to the second surface **10b** of the semiconductor substrate **10**.

(46) In the IGBT region **1a**, a p.sup.+ type collector layer **25** is disposed on the opposite side to the drift layer **11** with respect to the FS layer **24**. In the FWD region **1b**, an n.sup.+ type cathode layer **26** is disposed on the opposite side to the drift layer **11** with respect to the FS layer **24**. In other words, the collector layer **25** and the cathode layer **26** are disposed adjacent to each other on the opposite side to the drift layer **11** with respect to the FS layer **24**. The IGBT region **1a** and the FWD region **1b** are sectioned depending on whether the layer formed adjacent to the second surface **10b** of the semiconductor substrate **10** is the collector layer **25** or the cathode layer **26**. In the present embodiment, the region above the collector layer **25** serves as the IGBT region **1a**, and the region above the cathode layer **26** serves as the FWD region **1b**.

(47) A lower electrode **27** is disposed on an opposite side to the drift layer **11** with respect to the collector layer **25** and the cathode layer **26**. The lower electrode **27** is electrically connected to the collector layer **25** and the cathode layer **26**. The lower electrode **27** serves as a collector electrode in the IGBT region **1a** and serves as a cathode electrode in the FWD region **1b**. In the present

embodiment, the lower electrode 27 corresponds to a second electrode.

(48) The semiconductor device of the present embodiment is configured as described above. As such, the IGBT region **1a** constitutes an IGBT element including the base layer **12** as a base, the emitter region **18** as an emitter, and the collector layer **25** as a collector. Likewise, the FWD region **1b** constitutes a FWD element with PN junction including the base layer **12** as an anode, the drift layer **11**, the FS layer **24**, and the cathode layer **26** as a cathode.

(49) The configuration of the semiconductor device according to the present embodiment has been described above. In the present embodiment, the IGBT region **1a** and the FWD region **1b** are formed in the common semiconductor substrate **10** in this way. In the present embodiment, n type, n.sup.+ type, n.sup.++ type, and n.sup.- type correspond to a first conductivity type, and p type and p.sup.+ type correspond to a second conductivity type. Further, due to the configuration as described above, the semiconductor substrate **10** is configured to include the drift layer **11**, the base layer **12**, the barrier region **13**, the emitter region **18**, the contact region **19**, the FS layer **24**, the collector layer **25**, the cathode layer **26**, and the like.

(50) Next, operations and effects of the semiconductor device described above will be described.

(51) In the semiconductor device, when the lower electrode 27 is applied with a voltage higher than that of the upper electrode 23, the PN junction formed between the base layer **12** and the drift layer **11** is brought into a reverse conduction state to form a depletion layer. When the gate electrode **16** is applied with a low-level voltage (for example, 0 V) that is lower than a threshold voltage V_{th} of the insulated gate structure, a current does not flow between the upper electrode 23 and the lower electrode 27.

(52) In order to turn the IGBT element to an on state, a high-level voltage, which is equal to or higher than the threshold voltage V_{th} of the insulated gate structure, is applied to the gate electrode **16** in a state where the lower electrode 27 is applied with the voltage higher than that of the upper electrode 23. As a result, a channel region, which is an inversion layer, is formed in a portion of the base layer **12** being in contact with the gate trench **14** in which the gate electrode **16** is arranged. Then, in the IGBT element, electrons are supplied from the emitter region **18** to the drift layer **11** via the channel region, so that holes are supplied from the collector layer **25** to the drift layer **11**. As a result, as the resistance value of the drift layer **11** is lowered due to conductivity modulation, the IGBT element is turned to the on state.

(53) In the present embodiment, the emitter region **18** and the contact region **19** are arranged in the thickness direction of the semiconductor substrate **10**. Therefore, as compared with the configuration in which the emitter region **18** and the contact region **19** are arranged in the arrangement direction of the gate trenches **14**, the distance between the adjacent gate trenches **14** can be easily reduced, and thus the holes are difficult to escape. As such, the holes are easily accumulated in the drift layer **11**, and an injection enhancement (1E) effect can be improved, resulting in a reduction in the on-resistance.

(54) In order to turn the IGBT element in an off state and to turn the FWD element in an on state (i.e., to operate the FWD element as a diode), the voltages applied to the upper electrode 23 and the lower electrode 27 are switched, and a forward voltage is applied so that the upper electrode 23 is applied with a voltage higher than that of the lower electrode 27. As a result, holes are supplied to the base layer **12** and electrons are supplied to the cathode layer **26**, so that the FWD element operates as a diode.

(55) In the present embodiment, the semiconductor device is provided with the barrier region **13** and the connecting region **20**, and the connecting region **20** has the Schottky barrier junction with the upper electrode 23. When the FWD element is in the on state, the upper electrode 23 and the connecting region **20** (that is, the barrier region **13**) are short-circuited, so that holes are less likely injected from the upper electrode 23 into the drift layer **11** via the contact region **19**.

(56) Thereafter, in order to switch the FWD element from the on state to the off state, a reverse voltage is applied so that the lower electrode 27 is applied with a voltage higher than that of the

upper electrode **23**. In other words, in order to cut off the current in the state where the forward current is flowing in the FWD element, a reverse voltage is applied so that the lower electrode **27** is applied with the higher voltage than the upper electrode **23**. As a result, the FWD element is brought into a recovery state. The holes are attracted to the upper electrode **23** side and the electrons are attracted to the lower electrode **27** side, so the recovery current is generated.

(57) In the semiconductor device of the present embodiment, as described above, the hole injection is suppressed when the FWD element is in the on state. Therefore, the recovery current can be reduced and thus recovery loss can be reduced.

(58) According to the present embodiment described above, the upper electrode **23** has the Schottky barrier junction with the barrier region **13** via the connecting region **20**. Therefore, when the FWD element is in the on state, since the upper electrode **23** and the connecting region **20** are short-circuited, it is less likely that the holes will be injected from the upper electrode **23** to the drift layer **11** via the contact region **19**. As such, when the FWD element is turned off, the recovery current can be reduced and the recovery loss can be reduced.

(59) In the case of the RC-IGBT, it is conceivable to reduce the impurity concentration of the contact region **19** and the base layer **12** in order to suppress the hole injection from the contact region **19** and the base layer **12** of the IGBT region **1a** adjacent to the FWD region **1b**. In such a configuration, however, another issue such as a decrease in breakdown capacity of the IGBT element or a decrease in threshold voltage may arise.

(60) Therefore, the semiconductor device of the present embodiment, which can restrict the hole injection without reducing the impurity concentration of the contact region **19** and the base layer **12**, can suppress the reduction of the breakdown capacity of the IGBT element while suppressing the recovery loss.

(61) In the present embodiment, the emitter region **18** and the contact region **19** are arranged in the thickness direction of the semiconductor substrate **10**. Therefore, the distance between the adjacent gate trenches **14** can be easily reduced, as compared with the configuration in which the emitter region **18** and the contact region **19** are arranged in the arrangement direction of the gate trenches **14**. As such, it is possible to miniaturize the semiconductor device while reducing the on-resistance.

(62) In the present embodiment, the barrier region **13** and the upper electrode **23** disposed in the contact trench **17** are connected via the connecting region **20**. Therefore, as compared with the configuration in which the upper electrode **23** disposed in the contact trench **17** is directly connected to the barrier region **13**, a connection failure between the upper electrode **23** and the barrier region **13** can be suppressed even if the depth of the contact trench **17** is deviated.

Second Embodiment

(63) A second embodiment will be described hereinafter. In the present embodiment, the configuration of the FWD region **1b** is modified from that of the first embodiment. The other configurations are the same as those of the first embodiment, and therefore a description of the same configurations will be omitted below.

(64) In the semiconductor device of the present embodiment, as shown in FIG. **3**, the barrier region **13** is partially formed in the FWD region **1b**. In other words, the barrier region **13** is thinned out in the FWD region **1b**. That is, the barrier region **13** is not formed entirely in the FWD region **1b** along the planar direction of the semiconductor substrate **10**. Note that FIG. **3** is a cross-sectional view taken along the line II-II in FIG. **1**.

(65) According to the present embodiment described above, the emitter region **18** and the contact region **19** are arranged in the thickness direction of the semiconductor substrate **10**. Therefore, the same effect as that of the first embodiment can be obtained.

(66) In addition, in the present embodiment, the barrier region **13** is thinned out in the FWD region **1b**. Therefore, the hole injection is less suppressed in the FWD region **1b**, as compared with the first embodiment described above. As such, according to the semiconductor device of the present embodiment, it is possible to suppress an increase in the forward voltage of the FWD element, as

compared with the first embodiment described above. Note that the forward voltage of the FWD element can be reduced with an increase in the region where the barrier region **13** is thinned out. Therefore, in the FWD region **1b**, it is preferable to adjust the ratio of thinning out the barrier region **13** according to the intended use.

Modification of Second Embodiment

(67) A modification of the second embodiment will be described hereinafter. In the modification of the second embodiment, as shown in FIG. **4**, the barrier region **13** may be formed entirely in the FWD region **1b**, and the connecting region **20** may be thinned out in the FWD region **1b**. Even in such a semiconductor device, since the barrier region **13** is in a floating state in the region where the connecting region **20** is not formed, the similar effects to those of the second embodiment can be obtained.

Third Embodiment

(68) A third embodiment will be described hereinafter. In the present embodiment, the arrangement of the emitter region **18** and the contact region **19** is changed from that of the first embodiment. The other configurations are the same as those of the first embodiment, and therefore a description of the same configurations will be omitted below.

(69) In the semiconductor device of the present embodiment, as shown in FIGS. **5** and **6**, the emitter region **18** and the contact region **19** are not arranged in the thickness direction of the semiconductor substrate **10**, but are arranged as follows. That is, the emitter region **18** and the contact region **19** of the present embodiment are formed so as to be alternately arranged in the longitudinal direction of the gate trench **14** on the first surface **10a** of the semiconductor substrate **10**. Therefore, in the semiconductor device of the present embodiment, the first surface **10a** of the semiconductor substrate **10** is provided with the emitter regions **18** and the contact regions **19**. Note that FIG. **5** corresponds to a cross-sectional view taken along line II-II in FIG. **1**, and FIG. **6** corresponds to a cross-sectional view taken along line VI-VI in FIG. **1**.

(70) Such a semiconductor device is manufactured as follows. That is, ion implantation or the like is performed to the first surface **10a** of the semiconductor substrate **10** so as to form the emitter region **18** and the contact region **19**. Thereafter, the gate trench **14** and the contact trench **17** are formed. In this way, the semiconductor device of the present embodiment is manufactured.

(71) According to the present embodiment described above, the emitter region **18** and the contact region **19** are arranged in the longitudinal direction of the gate trench **14**. Therefore, as compared with the case where the emitter region **18** and the contact region **19** are arranged in the arrangement direction of the gate trenches **14**, the distance between the adjacent gate trenches **14** can be easily shortened, and thus the semiconductor device can be miniaturized. Further, the on-resistance can be reduced.

(72) In the present embodiment, the emitter region **18** and the contact region **19** are arranged in the longitudinal direction of the gate trench **14**. Therefore, in order to manufacture such a semiconductor device, the ion implantation or the like is performed to the first surface **10a** of the semiconductor substrate **10** to form the emitter region **18** and the contact region **19**, and then the gate trench **14**, the contact trench **17** and the like are formed. In this case, since the ion implantation is performed to the first surface **10a** of the semiconductor substrate **10**, the concentration of the contact region **19** can be easily controlled, as compared with the case where the ion implantation or the like is performed to the side surface of the contact trench **17** to form the contact region **19**. Further, in the semiconductor device of the present embodiment, even if the misalignment between the gate trench **14** and the contact trench **17** occurs, the overall misalignment can be made small, as compared with the case where the contact region **19** is formed after forming the contact trench **17**. As such, variations in characteristics can be reduced.

Fourth Embodiment

(73) A fourth embodiment will be described hereinafter. In the present embodiment, the shape of the connecting trench **22** is changed from that of the third embodiment. The other configurations

are the same as those of the third embodiment, and therefore a description of the same configurations will be omitted below.

(74) In the semiconductor device of the present embodiment, as shown in FIGS. 7 and 8, the contact trench **17** is thinned out in the longitudinal direction of the gate trench **14**. In other words, the contact trench **17** is partially formed in the longitudinal direction of the gate trench **14**. That is, the contact trench **17** is formed so as to be scattered or discontinuous in the longitudinal direction of the gate trench **14**. Note that FIG. 7 corresponds to a cross-sectional view taken along the line II-II in FIG. 1, and FIG. 8 is a cross-sectional view taken along the line VIII-VIII in FIG. 1.

(75) Specifically, the emitter region **18** and the contact region **19** are formed so as to be alternately arranged in the longitudinal direction of the gate trench **14**, as in the third embodiment. The contact trench **17** is formed so as to penetrate each contact region **19**, but not to penetrate the emitter region **18**. Therefore, in the contact region **19**, a portion exposed from the first surface **10a** of the semiconductor substrate **10** is also connected to the upper electrode **23**. In the present embodiment, the barrier metal portion **230a** is also formed in the portion between the adjacent contact trenches **17** on the first surface **10a** of the semiconductor substrate **10**.

(76) According to the present embodiment described above, since the emitter region **18** and the contact region **19** are arranged in the longitudinal direction of the gate trench **14**, the same effect as that of the third embodiment can be obtained.

(77) According to the present embodiment, the portion of the contact region **19** exposed from the first surface **10a** of the semiconductor substrate **10** is also connected to the upper electrode **23**. Therefore, as compared with the case where the contact region **19** is connected to the upper electrode **23** only on the side surface of the contact trench **17** and is formed by performing the ion implantation to the first surface **10a** of the semiconductor substrate **10** as in the third embodiment, the surface density of the contact region **19** relative to the upper electrode **23** can be increased. As such, the ohmic connection between the contact region **19** and the upper electrode **23** can be easily secured. Further, since the ohmic connection between the contact region **19** and the upper electrode **23** is easily secured, it is possible to suppress the potential of the portion of the base layer **12** located directly below the emitter region **18** from rising, and thus the latch-up resistance is improved.

Fifth Embodiment

(78) A fifth embodiment will be described hereinafter. In the present embodiment, the shape of the contact region **19** is changed from that of the fourth embodiment. The other configurations are the same as those of the fourth embodiment, and therefore a description of the same configurations will be omitted below.

(79) In the semiconductor device of the present embodiment, as shown in FIG. 9, the contact region **19** is formed to have the same depth as the contact trench **17**. Note that FIG. 9 corresponds to a cross-sectional view taken along the line VIII-VIII in FIG. 1.

(80) According to the present embodiment described above, since the emitter region **18** and the contact region **19** are arranged in the longitudinal direction of the gate trench **14**, the same effect as that of the third embodiment can be obtained.

(81) According to the present embodiment, the contact region **19** is formed to be the same depth as the contact trench **17**. Therefore, the connection area between the contact region **19** and the upper electrode **23** can be further increased, and the same effect as that of the fourth embodiment can be obtained. Further, since the ohmic connection between the contact region **19** and the upper electrode **23** can be easily secured, the distance between the contact regions **19** in the longitudinal direction of the gate trench **14** can be shortened. Moreover, the potential of the barrier region **13** can be stabilized.

Sixth Embodiment

(82) A sixth embodiment will be described hereinafter. The present embodiment is a combination of the first embodiment and the fifth embodiment. The other configurations are the same as those

of the first embodiment and the fifth embodiment, and thus the description thereof will be omitted below.

(83) In the semiconductor device of the present embodiment, as shown in FIGS. **10** and **11**, the contact trench **17** is formed by thinning out in the longitudinal direction of the gate trench **14**. Note that FIG. **10** corresponds to a cross-sectional view taken along the line II-II in FIG. **1**, and FIG. **11** corresponds to a cross-sectional view taken along the line VIII-VIII in FIG. **1**.

(84) The emitter region **18** is formed entirely over the first surface **10a** of the semiconductor substrate **10**. The contact region **19** is formed below the emitter region **18** so as to be in contact with the side surface of the contact trench **17**. The contact region **19** has the same depth as the contact trench **17**.

(85) According to the present embodiment described above, since the emitter region **18** and the contact region **19** are arranged in the thickness direction of the semiconductor substrate **10**, the same effect as that of the first embodiment can be obtained.

(86) In the present embodiment, since the contact region **19** is formed to the same depth as the contact trench **17**, the same effect as that of the fifth embodiment can be obtained.

Seventh Embodiment

(87) A seventh embodiment will be described hereinafter. In the present embodiment, the formation position of the semiconductor device is specified with respect to the configuration of the first embodiment. The other configurations are the same as those of the first embodiment, and therefore a description of the same configurations will be omitted below.

(88) In the semiconductor device provided with the RC-IGBT, when the FWD element is in the on state, as shown in FIG. **12**, the current flows as follows with reference to a boundary portion between the IGBT region **1a** and the FWD region **1b**. That is, the current flows from the boundary portion on the second surface **10b** toward the IGBT region **1a** with the angle θ relative to the second surface **10b** of the semiconductor substrate **10** being about 45° . Therefore, the portion of the IGBT region **1a** adjacent to the FWD region **1b** in which the current flows when the FWD element is in the on state affects the recovery loss. In the present embodiment, the portion of the IGBT region **1a** that affects the recovery loss (that is, the region in which the current flows when the FWD element is in the on state) is referred to as a second section **R2**. Further, a portion of the IGBT region **1a** that is different from the second section **R2** is referred to as a first section **R1**.

(89) In the semiconductor device of the present embodiment, the second section **R2** has the same configuration as the IGBT region **1a** described in the first embodiment.

(90) On the other hand, in the semiconductor device of the present embodiment, as shown in FIG. **13**, the first section **R1** is not formed with the connecting region **20** to be in contact with the bottom surface of the contact trench **17**. In the first section **R1**, the contact region **19** is formed to be in contact with the bottom surface of the contact trench **17**. According to this, the contact region **19** can be formed by ion implantation or the like into the bottom surface of the contact trench **17**. Therefore, the concentration of the contact region **19** can be easily controlled, as compared with the case where the contact region **19** is formed so as to be in contact with the side surface of the contact trench **17**. Although not particularly shown, the contact region **19** is formed so as to be also in contact with the side surface of the gate trench **14**. Further, the distance between the adjacent gate trenches **14** may be different between the first section **R1** and the second section **R2**. For example, the distance between the adjacent gate trenches **14** in the first section **R1** may be larger than that in the second section **R2**.

(91) As in the present embodiment described above, the IGBT region **1a** may have a different configuration between the first section **R1** and the second section **R2**, and the second section **R2** may have the same configuration as the IGBT region **1a** of the first embodiment.

Modification of Seventh Embodiment

(92) A modification of the seventh embodiment will be described hereinafter. In the present embodiment, the second section **R2** of the IGBT region **1a** may have the same configuration as the

IGBT region **1a** of the third to sixth embodiments. As shown in FIGS. **14** and **15**, the FWD region **1b** may not be formed with the contact trench **17** and the connecting region **20**. In the surface layer portion of the base layer **12**, the contact region **19** connected to the upper electrode **23** may be formed partially in the longitudinal direction of the gate trench **14**. Note that FIG. **14** corresponds to a cross-sectional view taken along the line XVI-XVI in FIG. **1**, and FIG. **15** corresponds to a cross-sectional view taken along the line XV-XV in FIG. **1**. Further, although not particularly shown, the configuration of the FWD region **1b** can be appropriately changed. For example, the gate trench **14** may not be formed or the emitter region **18** may not be formed.

Other Embodiments

(93) Although the present disclosure has been described in accordance with the embodiments, it is understood that the present disclosure is not limited to such embodiments or structures. The present disclosure encompasses various modifications and variations within the scope of equivalents. In addition, various combinations and configurations, as well as other combinations and configurations that include only one element, more, or less, are within the scope and spirit of the present disclosure.

(94) For example, in each of the embodiments described above, the example in which the first conductivity type is the n type and the second conductivity type is the p type has been described. Alternatively, the first conductivity type may be the p type and the second conductivity type may be the n type.

(95) In each of the embodiments described above, the number of the cell region **1** may be one, or may be three or more. Further, only one FWD region **1b** may be formed in one cell region **1**.

(96) The embodiments described above can be combined as appropriate. For example, in the first, third to sixth embodiments, the configuration of the FWD region **1b** may be the same configuration as the second embodiment or the seventh embodiment, or may be another configuration. Further, the combinations of the above embodiments may be further combined. That is, the embodiments described above may be combined in various ways.

Claims

1. A semiconductor device comprising: a semiconductor substrate including an IGBT region having an IGBT element and a FWD region having an FWD element, the semiconductor substrate having a first conductivity type drift layer, a second conductivity type base layer disposed on the drift layer, a second conductivity type collector layer disposed opposite to the base layer with respect to the drift layer in the IGBT region, and a first conductivity type cathode layer disposed opposite to the base layer with respect to the drift layer in the FWD region, the semiconductor substrate having a first surface adjacent to the base layer and a second surface opposite to the first surface and adjacent to the collector layer and the cathode layer; a gate insulating film disposed on a wall surface of each of a plurality of gate trenches disposed in the semiconductor substrate in the IGBT region, each of the plurality of gate trenches passing through the base layer to reach the drift layer and extending in one direction as a longitudinal direction along a planar direction of the semiconductor substrate, the plurality of gate trenches being arranged in an arrangement direction that intersects with the longitudinal direction; a gate electrode disposed on the gate insulating film; a first conductivity type emitter region disposed in a surface layer portion of the base layer in the IGBT region to be in contact with each of the gate trenches, the emitter region having a higher impurity concentration than the drift layer; a second conductivity type contact region disposed in the base layer in the IGBT region, the contact region having a higher impurity concentration than the base layer; a first electrode disposed adjacent to the first surface of the semiconductor substrate, the first electrode being electrically connected to the base layer and the emitter region; a second electrode disposed adjacent to the second surface of the semiconductor substrate, the second electrode being electrically connected to the collector layer and the cathode layer; and a first

conductivity type barrier region disposed above the drift layer in the IGBT region, the barrier region having a higher impurity concentration than the drift layer, wherein the semiconductor substrate is formed with a contact trench between adjacent gate trenches in the IGBT region, the contact trench having a bottom surface closer to the first surface of the semiconductor substrate than the barrier region is to the first surface, the first electrode is embedded in the contact trench, the semiconductor device further comprising: a first conductivity type connecting region between the bottom surface of the contact trench and the barrier region in the IGBT region, the connecting region being connected to the barrier region and the first electrode and having a higher impurity concentration than the drift layer, wherein the emitter region and the contact region are arranged in a direction different from the arrangement direction.

2. The semiconductor device according to claim 1, wherein the emitter region is disposed to be exposed from the first surface of the semiconductor substrate, the contact region is disposed to be exposed from a side surface of the contact trench in a position between the emitter region and the barrier region, and the contact region and the emitter region are arranged in a thickness direction of the semiconductor substrate.

3. The semiconductor device according to claim 1, wherein the emitter region and the contact region are alternately arranged in the longitudinal direction.

4. The semiconductor device according to claim 1 wherein the contact trench is extended in the longitudinal direction.

5. The semiconductor device according to claim 1, wherein the contact trench is disposed partially in the longitudinal direction.

6. The semiconductor device according to claim 1, wherein the contact region has a same depth as the contact trench.

7. The semiconductor device according to claim 1, wherein the emitter region and the contact region are arranged in a thickness direction of the semiconductor substrate so that a bottom of the contact region is located lower than a bottom of the emitter region.

8. The semiconductor device according to claim 1, wherein the emitter region and the contact region are arranged in the longitudinal direction.
