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Semiconductor device and method of manufacturing the same

Abstract

A semiconductor device includes: a semiconductor substrate; a plurality of trenches provided on a top surface side of the semiconductor substrate; an insulated gate electrode structure buried inside the respective trenches; an interlayer insulating film deposited on top surfaces of the semiconductor substrate and the insulated gate electrode structure; and a silicide layer deposited at a bottom of a contact hole penetrating the interlayer insulating film so as to be in contact with the top surface of the semiconductor substrate interposed between the trenches adjacent to each other, wherein at least a part of a bottom surface of the silicide layer is located at a higher position than a bottom surface of the interlayer insulating film.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

(1) This application claims benefit of priority under 35 USC 119 based on Japanese Patent Application No. 2022-022943 filed on Feb. 17, 2022, the entire contents of which are incorporated by reference herein.

BACKGROUND OF THE INVENTION

1. Field of the Invention

(2) The present invention relates to a semiconductor device and a method of manufacturing the semiconductor device.

2. Description of the Related Art

(3) Conventional trench-gate metal-oxide-semiconductor field-effect transistors (MOSFETs) or insulated gate bipolar transistors (IGBTs) have a configuration in which an interlayer insulating film provided on a mesa part interposed between trenches adjacent to each other is provided with penetration holes (contact holes) so that the mesa part is exposed in order to connect the mesa part with a source electrode or an emitter electrode. A film of barrier metal including a titanium film and a titanium nitride film is deposited inside the contact holes, and the contact holes are further filled with a tungsten film. Thereafter, the source electrode or the emitter electrode is further deposited on the tungsten film. To prevent a spread of tungsten (W) of the tungsten film toward silicon (Si) of the mesa part and to enhance adhesiveness, the titanium film deposited at the bottom of the contact holes is subjected to silicidation to form a titanium silicide layer before the tungsten film is buried.

(4) WO 2020/036015 A1 discloses a semiconductor device including a transistor part and a diode part, and having a life-time control region inside a semiconductor substrate. JP 2011-181840 A discloses a configuration in which a first metal film of barrier metal included in a front-surface electrode provided on the entire surface of a cell region provided with an IGBT is formed of metallic material of the VIII group such as nickel and cobalt. JP 2002-198325 A discloses a configuration in which contact holes are formed so that a silicon thin film and barrier metal are sequentially deposited or the barrier metal and the silicon thin film are sequentially deposited in the contact holes, and heat treatment is then executed so as to form silicide.

(5) JP H4-320329 A discloses forming a silicon layer on a semiconductor substrate at the bottom of a contact hole, forming a refractory metal silicide layer, and forming a metal film. JP H11-121396 A discloses forming a silicon film on a surface of a silicon layer, forming a titanium film on the silicon film, and reacting the silicon film and the titanium film by heat treatment to form a TiSi₂ film. JP 2013-175707 A discloses an irradiation step of irradiating a particle beam or radiation from a main surface side of a semiconductor substrate, and an annealing step for recovering crystal defects contained in a gate insulating film and a gate electrode after the irradiation step. JP2019-114705 A discloses forming a trench on a surface of a semiconductor substrate, hydrogen-terminating dangling bonds of atoms in an inner surface of the trench, forming a first insulating film and a second insulating film on the inner surface of the trench, and forming a gate electrode inside of the trench. JP 2020-013828 A discloses a semiconductor device including a semiconductor substrate, an interlayer insulating film disposed on an upper surface of the semiconductor substrate, a titanium layer provided on the interlayer insulating film, and a titanium nitride layer provided on the titanium layer. The interlayer insulating film has an opening that exposes a portion of the upper surface of the semiconductor substrate, and the titanium layer and the titanium nitride layer are also provided in the opening. The titanium layer that is arranged in contact with the semiconductor substrate at the bottom of the opening is entirely titanium silicided.

(6) JP 2007-335554 A discloses forming a Ti film on a bottom surface and a side wall surface of a contact, forming a Ti silicide film on the bottom surface by annealing treatment, forming a TiN

film on the bottom surface and side wall after removing an unreacted Ti film, phase transitioning the Ti silicide film by annealing treatment again, and depositing tungsten in a remaining space of the contact hole to form a tungsten plug. JP 2019-096848 A discloses a semiconductor device including a contact hole that penetrates an interlayer insulating layer and a gate insulating layer and the exposes part of the surface of a semiconductor substrate, a metal layer covering an upper surface of the interlayer insulating layer, an inner side surface of the contact hole, and the exposed part of the semiconductor substrate, and a source wiring connected through a contact hole to a part of the metal layer covering at least the exposed part of the surface of the semiconductor substrate. JP 2021-064673 A discloses a semiconductor device in which a lifetime control region including a lifetime killer is provided below a base region in a semiconductor substrate, extending from at least a portion of a transistor portion to a diode portion. JP 6950779 B discloses a semiconductor device in which an upper surface side lifetime reduction region is provided on an upper surface side of a semiconductor substrate in a diode section.

(7) When the titanium film at the bottom of the contact holes is subjected to silicidation to form the titanium silicide layer, titanium (Ti) of the titanium film reacts with silicon (Si) in the mesa part, and the volume of the mesa part is thus decreased, which leads the contact holes to expand to a part under an interlayer insulating film, causing eaves (overhangs) in the interlayer insulating film. Such a case may impede the appropriate formation of the metal film such as a titanium nitride film or a tungsten film inside the contact holes after the formation of the titanium silicide layer. This may result in a spread of tungsten (W) of the tungsten film toward silicon (Si) in the mesa part.

SUMMARY OF THE INVENTION

(8) In view of the foregoing problems, the present invention provides a semiconductor device and a method manufacturing the semiconductor device capable of satisfactorily forming a metal film inside a contact hole of an interlayer insulating film when forming a silicide layer at a bottom of the contact hole.

(9) An aspect of the present invention inheres in a semiconductor device including: a semiconductor substrate; a plurality of trenches provided on a top surface side of the semiconductor substrate; an insulated gate electrode structure buried inside the respective trenches; an interlayer insulating film deposited on top surfaces of the semiconductor substrate and the insulated gate electrode structure; and a silicide layer deposited at a bottom of a contact hole penetrating the interlayer insulating film so as to be in contact with the top surface of the semiconductor substrate interposed between the trenches adjacent to each other, wherein at least a part of a bottom surface of the silicide layer is located at a higher position than a bottom surface of the interlayer insulating film.

(10) Another aspect of the present invention inheres in a method of a semiconductor device including: digging a plurality of trenches from a top surface side of a semiconductor substrate; burying an insulated gate electrode structure in the respective trenches; depositing an interlayer insulating film on top surfaces of the semiconductor substrate and the insulated gate electrode structure; forming a contact hole in the interlayer insulating film located on the semiconductor substrate interposed between the respective trenches; and forming a silicide layer inside the contact hole such that at least a part of a bottom surface of the silicide layer is located at a higher position than a bottom surface of the interlayer insulating film.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. 1 is a plan view illustrating an example of a semiconductor device according to a first embodiment;

(2) FIG. 2 is a cross-sectional view as viewed from A-A line in FIG. 1;

- (3) FIG. 3 is an enlarged view of region A in FIG. 2;
- (4) FIG. 4 is a cross-sectional view for explaining an example of a method of manufacturing the semiconductor device according to the first embodiment;
- (5) FIG. 5 is a cross-sectional view continued from FIG. 4 for explaining the example of the method of manufacturing the semiconductor device according to the first embodiment;
- (6) FIG. 6 is a cross-sectional view continued from FIG. 5 for explaining the example of the method of manufacturing the semiconductor device according to the first embodiment;
- (7) FIG. 7 is a cross-sectional view continued from FIG. 6 for explaining the example of the method of manufacturing the semiconductor device according to the first embodiment;
- (8) FIG. 8 is a cross-sectional view continued from FIG. 7 for explaining the example of the method of manufacturing the semiconductor device according to the first embodiment;
- (9) FIG. 9 is a cross-sectional view continued from FIG. 8 for explaining the example of the method of manufacturing the semiconductor device according to the first embodiment;
- (10) FIG. 10 is a cross-sectional view continued from FIG. 9 for explaining the example of the method of manufacturing the semiconductor device according to the first embodiment;
- (11) FIG. 11 is a cross-sectional view continued from FIG. 10 for explaining the example of the method of manufacturing the semiconductor device according to the first embodiment;
- (12) FIG. 12 is a cross-sectional view continued from FIG. 11 for explaining the example of the method of manufacturing the semiconductor device according to the first embodiment;
- (13) FIG. 13 is a cross-sectional view for explaining a method of manufacturing a semiconductor device of a comparative example;
- (14) FIG. 14 is a cross-sectional view continued from FIG. 13 for explaining the method of manufacturing the semiconductor device of the comparative example;
- (15) FIG. 15 is a cross-sectional view continued from FIG. 14 for explaining the method of manufacturing the semiconductor device of the comparative example;
- (16) FIG. 16 is a cross-sectional view continued from FIG. 15 for explaining the method of manufacturing the semiconductor device of the comparative example;
- (17) FIG. 17 is a cross-sectional view continued from FIG. 16 for explaining the method of manufacturing the semiconductor device of the comparative example;
- (18) FIG. 18 is a cross-sectional view for explaining a method of manufacturing a semiconductor device according to a first modified example of the first embodiment;
- (19) FIG. 19 is a cross-sectional view for explaining a method of manufacturing a semiconductor device according to a second modified example of the first embodiment;
- (20) FIG. 20 is a cross-sectional view continued from FIG. 19 for explaining the method of manufacturing the semiconductor device according to the second modified example of the first embodiment;
- (21) FIG. 21 is a cross-sectional view for explaining a method of manufacturing a semiconductor device according to a third modified example of the first embodiment;
- (22) FIG. 22 is a cross-sectional view continued from FIG. 21 for explaining the method of manufacturing the semiconductor device according to the third modified example of the first embodiment;
- (23) FIG. 23 is a cross-sectional view for explaining a method of manufacturing a semiconductor device according to a fourth modified example of the first embodiment;
- (24) FIG. 24 is a cross-sectional view continued from FIG. 23 for explaining the method of manufacturing the semiconductor device according to the fourth modified example of the first embodiment;
- (25) FIG. 25 is a cross-sectional view continued from FIG. 24 for explaining the method of manufacturing the semiconductor device according to the fourth modified example of the first embodiment;
- (26) FIG. 26 is a cross-sectional view illustrating a semiconductor device according to a fifth

modified example of the first embodiment;

(27) FIG. 27 is a cross-sectional view illustrating an example of a semiconductor device according to a second embodiment;

(28) FIG. 28 is a cross-sectional view for explaining an example of a method of manufacturing the semiconductor device according to the second embodiment;

(29) FIG. 29 is a cross-sectional view continued from FIG. 28 for explaining the example of the method of manufacturing the semiconductor device according to the second embodiment; and

(30) FIG. 30 is a cross-sectional view continued from FIG. 29 for explaining the example of the method of manufacturing the semiconductor device according to the second embodiment.

DETAILED DESCRIPTION

(31) With reference to the Drawings, first and second embodiments of the present invention will be described below. In the Drawings, the same or similar elements are indicated by the same or similar reference numerals. The Drawings are schematic, and it should be noted that the relationship between thickness and planer dimensions, the thickness proportion of each layer, and the like are different from real ones. Accordingly, specific thicknesses or dimensions should be determined with reference to the following description. Moreover, in some drawings, portions are illustrated with different dimensional relationships and proportions.

(32) As used in the present specification, a source region of a MOSFET is “one main region (a first main region)” that can be used as an emitter region of an insulated gate bipolar transistor (IGBT). The “one main region”, when provided in a thyristor such as a MOS controlled static induction thyristor (SI thyristor), can be used as a cathode region. A drain region of the MOSFET is “another main region (a second main region)” of the semiconductor device that can be used as a collector region in the IGBT and as an anode region in the SI thyristor. The term “main region”, when simply mentioned in the present specification, is referred to as either the first main region or the second main region that is determined as appropriate by the person skilled in the art.

(33) Further, definitions of directions such as an up-and-down direction in the following description are merely definitions for convenience of understanding, and are not intended to limit the technical ideas of the present invention. For example, as a matter of course, when the subject is observed while being rotated by 90°, the subject is understood by converting the up-and-down direction into the right-and-left direction. When the subject is observed while being rotated by 180°, the subject is understood by inverting the up-and-down direction.

(34) Further, in the following description, there is exemplified a case where a first conductivity type is an n-type and a second conductivity type is a p-type. However, the relationship of the conductivity types may be inverted to set the first conductivity type to the p-type and the second conductivity type to the n-type. Further, a semiconductor region denoted by the symbol “n” or “p” attached with “+” indicates that such semiconductor region has a relatively high impurity concentration as compared to a semiconductor region denoted by the symbol “n” or “p” without “+”. A semiconductor region denoted by the symbol “n” or “p” attached with “-” indicates that such semiconductor region has a relatively low impurity concentration as compared to a semiconductor region denoted by the symbol “n” or “p” without “-”. However, even when the semiconductor regions are denoted by the same reference symbols “n” and “n”, it is not indicated that the semiconductor regions have exactly the same impurity concentration.

First Embodiment

(35) <Configuration of Semiconductor Device>

(36) FIG. 1 is a plan view illustrating a part of an active region of a semiconductor device according to a first embodiment as viewed from the top surface (the front surface) side. As illustrated in FIG. 1, the semiconductor device according to the first embodiment includes a transistor part 101 including a transistor element such as an IGBT and a diode part 102 including a diode element, which are integrated on the same semiconductor chip. For example, the semiconductor device according to the first embodiment is a reverse-conducting IGBT (RC-IGBT)

including an IGBT corresponding to the transistor part **101** and a free-wheeling diode (FWD) corresponding to the diode part **102** connected antiparallel to the IGBT that are integrated on the same semiconductor chip. The transistor part **101** and the diode part **102** may be arranged alternately in the right-left direction in FIG. **1**.

(37) FIG. **2** is a cross-sectional view taken along line A-A cross-sectioned across the transistor part **101** and the diode part **102** in FIG. **1**. As illustrated in FIG. **2**, the semiconductor device according to the first embodiment includes a semiconductor substrate **10**. The semiconductor substrate **10** is a silicon (Si) substrate, for example. The semiconductor substrate **10** is not limited to the Si substrate, and may be a semiconductor substrate of a semiconductor (a wide band-gap semiconductor) having a wider band gap than Si, such as silicon carbide (SiC), gallium nitride (GaN), diamond (C), or aluminum nitride (AlN).

(38) The semiconductor substrate **10** includes a drift layer **1** of a first conductivity-type (n.sup.-type). An accumulation layer **2** of n-type is deposited on the top surface side of the drift layer **1** and having a higher impurity concentration than the drift layer **1** in the transistor part **101**. The bottom surface of the accumulation layer **2** is in contact with the top surface of the drift layer **1**. The presence of the accumulation layer **2** can enhance the effect of promoting the injection of carriers (an IE effect) so as to decrease an ON-voltage.

(39) The transistor part **101** is provided with a base region **3** of a second conductivity-type (p.sup.+type) deposited on the top surface side of the accumulation layer **2**. The bottom surface of the base region **3** is in contact with the top surface of the accumulation layer **2**. A first main region (an emitter region) **4** of n.sup.+type is deposited on the top surface side of the base region **3**. The bottom surface of the emitter region **4** is in contact with the top surface of the base region **3**. The emitter region **4** has a higher impurity concentration than the drift layer **1** and the accumulation layer **2**.

(40) The n-type accumulation layer **2** is deposited on the top surface side of the drift layer **1** and having a higher impurity concentration than the drift layer **1** in the diode part **102**. The diode part **102** is not necessarily provided with the accumulation layer **2**. The bottom surface of the accumulation layer **2** is in contact with the top surface of the drift layer **1**. An anode region **13** of p.sup.-type is deposited on the top surface side of the accumulation layer **2**. The bottom surface of the anode region **13** is in contact with the top surface of the accumulation layer **2**. The anode region **13** has the top surface that is the same level as the top surface of the semiconductor substrate **10**. The anode region **13** may be deposited to have the same depth and the same impurity concentration as the base region **3** in the transistor part **101**.

(41) A plurality of trenches **11** are provided separately from each other extending from the top surface of the semiconductor substrate **10** in the depth direction in each of the transistor part **101** and the diode part **102**. The respective trenches **11** in the transistor part **101** penetrate the emitter region **4**, the base region **3**, and the accumulation layer **2** to reach the drift layer **1**. The respective side surfaces of the emitter region **4**, the base region **3**, and the accumulation layer **2** are in contact with the side surfaces of the respective trenches **11**. The respective trenches **11** in the diode part **102** penetrate the anode region **13** and the accumulation layer **2** to reach the drift layer **1**. The respective side surfaces of the anode region **13** and the accumulation layer **2** are in contact with the side surfaces of the respective trenches **11**.

(42) The region between the respective trenches **11** adjacent to each other is provided with a mesa part implemented by the upper part of the semiconductor substrate **10**. The mesa part is a region of the semiconductor substrate **10** interposed between the respective trenches **11** adjacent to each other, and is located at a higher position than the deepest position of the trenches **11**. The upper part of the drift layer **1**, the accumulation layer **2**, the base region **3**, and the emitter region **4** are provided in the mesa part in the transistor part **101**. The upper part of the drift layer **1**, the accumulation layer **2**, and the anode region **13** are provided in the mesa part in the diode part **102**.

(43) A gate insulating film **6** is provided to cover the bottom surfaces and the side surfaces of the

respective trenches **11**. The gate insulating film **6** to be used can be a single film of a silicon dioxide film (a SiO₂ film), a silicon oxynitride (SiON) film, a strontium oxide (SrO) film, a silicon nitride (Si₃N₄) film, an aluminum oxide (Al₂O₃) film, a magnesium oxide (MgO) film, an yttrium oxide (Y₂O₃) film, a hafnium oxide (HfO₂) film, a zirconium oxide (ZrO₂) film, a tantalum oxide (Ta₂O₅) film, or a bismuth oxide (Bi₂O₃) film, or a composite film including some of the above single films stacked on one another.

(44) A gate electrode **7** is buried inside the respective trenches **11** via the gate insulating film **6**. The gate insulating film **6** and the gate electrode **7** implement an insulated gate electrode structure (**6**, **7**). The material used for the gate electrode **7** may be a polysilicon film (a doped polysilicon film) with which impurity ions such as phosphorus (P) or boron (B) are heavily doped, for example.

(45) A part of the plural insulated gate electrode structures (**6**, **7**) in the transistor part **101** may be a gate trench connected to a gate runner, and the other may be a dummy trench not connected to the gate runner. The plural insulated gate electrode structures (**6**, **7**) in the diode part **102** may each be a dummy trench not connected to the gate runner.

(46) As illustrated in FIG. **1**, the plural trenches **11** each have a straight (stripe-shaped) part extending parallel to each other in one direction (the upper-lower direction in FIG. **1**) in the planar pattern. A contact region **5** of p⁺-type and the emitter region **4** of n⁺-type are alternately and repeatedly arranged parallel to the extending direction (the longitudinal direction) of the respective trenches **11** in the transistor part **101**. The contact region **5** is in contact with the emitter region **4**. The contact region **5** is deposited on the top surface side of the base region **3** illustrated in FIG. **2**. The bottom surface of the contact region **5** is in contact with the top surface of the base region **3**. The contact region **5** has a higher impurity concentration than the base region **3**. The anode region **13** in the diode part **102** has a straight (stripe-shaped) part extending parallel to the extending direction of the respective trenches **11**.

(47) As illustrated in FIG. **2**, an interlayer insulating film **20** is deposited on the top surfaces of the semiconductor substrate **10** and the respective insulated gate electrode structures (**6**, **7**). The interlayer insulating film **20** is a single film of a silicon oxide film (a SiO₂ film) without containing phosphorus (P) or boron (B) which is referred to as a non-doped silicate glass (NSG) film, a phosphosilicate glass (PSG) film, a borosilicate glass (BSG) film, a borophosphosilicate glass (BPSG) film, or a silicon nitride (Si₃N₄) film, or a stacked layer of the above films stacked on one another.

(48) The interlayer insulating film **20** located on the mesa part of the semiconductor substrate **10** is provided with contact holes **20a** penetrating the interlayer insulating film **20**. A connection conductor (a contact plug) **30** is buried in the respective contact holes **20a**. The bottom surface of the respective connection conductors **30** is in contact with the respective top surfaces of the emitter region **4** and the contact region **5** in the transistor part **101**. The bottom surface of the respective connection conductors **30** is in contact with the top surface of the anode region **13** in the diode part **102**.

(49) A front-surface electrode **40** is deposited on the interlayer insulating film **20**. The front-surface electrode **40** in the transistor part **101** is electrically connected to the emitter region **4** and the contact region **5** via the respective connection conductors **30** so as to serve as an emitter electrode. The front-surface electrode **40** in the diode part **102** is electrically connected to the anode region **13** via the respective connection conductors **30** so as to serve as an anode electrode.

(50) FIG. **1** omits the illustration of the interlayer insulating film **20**, the connection conductors **30**, and the front-surface electrode **40** illustrated in FIG. **2**. FIG. **1** schematically indicates the positions of the contact holes **20a** of the interlayer insulating film **20** illustrated in FIG. **2** by the broken lines. The contact holes **20a** each have a straight (stripe-shaped) part extending parallel to the longitudinal direction of the respective trenches **11** in the planar pattern. The respective contact holes **20a** in the transistor part **101** are provided on the top surface side of the emitter region **4** and

the contact region **5**. The respective contact holes **20a** in the diode part **102** are provided on the top surface side of the anode region **13**.

(51) FIG. **3** illustrates the cross section enlarging the region A including the connection conductor **30** in the transistor part **101** illustrated in FIG. **2**. The cross section enlarging the region including the connection conductor **30** in the diode part **102** illustrated in FIG. **2** has the same structure as the cross section illustrated in FIG. **3**.

(52) As illustrated in FIG. **3**, a projection **4a** is provided at the upper part of the emitter region **4**. The projection **4a** is located separately from the trenches **11** substantially at the middle position of the mesa part interposed between the trenches **11** adjacent to each other. The projection **4a** has a height **h1** set in a range of about 20 nanometers or greater and 300 nanometers or less, for example. The projection **4a** has a width **w1** set in a range of about 20% or greater and 90% or less of a width **w2** of the mesa part, for example.

(53) The similar projection is also provided at the upper part of the contact region **5** illustrated in FIG. **1**. The projection has a straight (stripe-shaped) part extending parallel to the longitudinal direction of the respective trenches **11** in the planar pattern substantially at the middle position of the mesa part interposed between the trenches **11** adjacent to each other.

(54) As illustrated in FIG. **3**, the interlayer insulating film **20** includes a first insulating film **21** deposited on the top surface side of the insulated gate electrode structure (**6**, **7**) and the emitter region **4**, and a second insulating film **22** deposited on the top surface side of the first insulating film **21**. The first insulating film **21** is a high temperature oxide (HTO) film, and the second insulating film **22** is a BPSG film, for example. The second insulating film **22** has a greater thickness than the first insulating film **21**. While FIG. **3** illustrates the case in which the interlayer insulating film **20** has the double-layer structure, the interlayer insulating film may have a single-layer structure or may have a multi-layer structure including three or more layers stacked on one another.

(55) The contact hole **20a** of the interlayer insulating film **20** has a tapered shape with a width gradually decreased from the upper side to the lower side, for example. The top surface of the projection **4a** is exposed on the bottom surface of the contact hole **20a**. The width of the bottom surface of the contact hole **20a** substantially conforms to the width **w1** of the projection **4a**. The side surface of the projection **4a** is in contact with the side surface of the first insulating film **21**. The top surface of the projection **4a** is located at a higher position than the bottom surface **20b** of the interlayer insulating film **20** that is the bottom surface of the first insulating film **21**.

(56) The connection conductor **30** is buried in the contact hole **20a**. The connection conductor **30** includes a titanium silicide layer **31** that is a silicide layer including titanium silicide (TiSi_{sub}.2), a titanium nitride film **32** that is a barrier metal film including titanium nitride (TiN), and a tungsten film **33** that is a metal film including tungsten (W).

(57) The titanium silicide layer **31** has a thickness set in a range of about 20 nanometers or greater and 80 nanometers or less, for example. The titanium nitride film **32** has a thickness set in a range of about 20 nanometers or greater and 140 nanometers or less, for example. The tungsten film **33** has a thickness set in a range of about 100 nanometers or greater and 1500 nanometers or less, for example.

(58) The titanium silicide layer **31** is deposited at the bottom of the contact hole **20a**. The bottom surface **31a** of the titanium silicide layer **31** is in contact with the top surface of the projection **4a**. The side surface of the titanium silicide layer **31** is in contact with the first insulating film **21**. FIG. **3** illustrates the case in which the bottom surface **31a** of the titanium silicide layer **31** is flat, and the entire bottom surface **31a** of the titanium silicide layer **31** is located at a higher position than the bottom surface **20b** of the interlayer insulating film **20**.

(59) At least the edge part of the bottom surface **31a** the titanium silicide layer **31** in contact with the first insulating film **21** is only required to be located at the higher position than the bottom surface **20b** of the interlayer insulating film **20**. For example, the titanium silicide layer **31** may

have a structure in which the bottom surface **31a** has a convex shape projecting downward so that the middle part of the bottom surface **31a** is located at a lower position than the edge part and is located at a lower position than the bottom surface **20b** of the interlayer insulating film **20**.

(60) The titanium nitride film **32** is provided to cover the top surface of the titanium silicide layer **31** and the side surface of the contact hole **20a**. The bottom surface of the titanium nitride film **32** located at the bottom of the contact hole **20a** is in contact with the top surface of the titanium silicide layer **31**. The titanium nitride film **32** located on the side surface of the contact hole **20a** is in contact with the respective side surfaces of the first insulating film **21** and the second insulating film **22**.

(61) The tungsten film **33** is deposited in the contact hole **20a** via the titanium nitride film **32** and the titanium silicide layer **31** so as to fill the contact hole **20a**. The titanium nitride film **32** and the tungsten film **33** may be not only provided in the contact hole **20a** but further extend along the top surface of the second insulating film **22**.

(62) The front-surface electrode **40** is deposited on the respective top surfaces of the titanium nitride film **32**, the tungsten film **33**, and the second insulating film **22**. The front-surface electrode **40** is electrically connected to the emitter region **4** via the connection conductor **30**. The front-surface electrode **40** can be formed of metal such as aluminum (Al), an aluminum alloy, and copper (Cu). Examples of the aluminum alloy include Al-silicon (Si), Al-copper (Cu)—Si, and Al—Cu.

(63) As illustrated in FIG. 2, a life-time control region **60** is provided inside the drift layer **1**. The life-time control region **60** is provided uniformly across the entire area of the transistor part **101** and the diode part **102**. The life-time control region **60** may be only provided selectively in the diode part **102** without being provided in the transistor part **101**. Alternatively, the life-time control region **60** may be provided selectively in a part of the transistor part **101**.

(64) The life-time control region **60** is composed of crystal defects (point defects) of helium (He) or protons (hydrogen) implanted as a life-time killer. The presence of the life-time control region **60** can improve and enhance the properties of the semiconductor device.

(65) A buffer layer **8** of n-type having a higher impurity concentration than the drift layer **1** is deposited on the bottom surface side of the drift layer **1** in the transistor part **101** and the diode part **102**. The top surface of the buffer layer **8** is in contact with the bottom surface of the drift layer **1**. The buffer layer **8** functions as a field-stop layer that prevents a depletion layer that spreads from the bottom surface side of the base region **3** and the anode region **13** from reaching a second main region (a collector region) **9** and a cathode region **12** described below.

(66) The collector region **9** of p.sup.+ -type is deposited on the bottom surface side of the buffer layer **8** in the transistor part **101**. The top surface of the collector region **9** is in contact with the bottom surface of the buffer layer **8**. The collector region **9** has a higher impurity concentration than the base region **3**. The cathode region **12** of n.sup.+ -type having a higher impurity concentration than the buffer layer **8** is deposited on the bottom surface side of the buffer layer **8** in the diode part **102**. The top surface of the cathode region **12** is in contact with the bottom surface of the buffer layer **8**. The cathode region **12** is deposited at the same level as the buffer layer **8**. The side surface of the cathode region **12** is in contact with the side surface of the collector region **9**.

(67) A rear-surface electrode **50** is deposited on the bottom surface side of the collector region **9** and the cathode region **12**. The rear-surface electrode **50** can be a single film of gold (Au), or a metal film including titanium (Ti), nickel (Ni), and gold (Au) stacked in this order, for example. The rear-surface electrode **50** functions as a collector electrode in the transistor part **101**, and functions as a cathode electrode in the diode part **102**.

(68) In the transistor part **101**, when a positive voltage is applied to the rear-surface electrode **50** while the front-surface electrode **40** is used as a ground potential, and a positive voltage of a threshold or greater is applied to the gate electrode **7**, an inversion layer (a channel) is formed in the base region **3** toward the side surface of the respective trenches **11**, and the transistor part **101** is thus turned ON. In the ON-state, a current flows from the rear-surface electrode **50** to the front-

surface electrode **40** through the collector region **9**, the buffer layer **8**, the drift layer **1**, the accumulation layer **2**, the inversion layer of the base region **3**, and the emitter region **4**. When the voltage applied to the gate electrode **7** is less than the threshold, no inversion layer is provided in the base region **3**, and the transistor part **101** is thus in the OFF-state, which does not cause the current to flow from the rear-surface electrode **50** toward the front-surface electrode **40**. The diode part **102** then leads a free-wheeling current to flow to cause an electrical conduction in the reverse direction when the transistor part **101** is turned OFF.

(69) <Method of Manufacturing Semiconductor Device>

(70) An example of a method of manufacturing the semiconductor device according to the first embodiment is described below with reference to FIG. **1** to FIG. **12**. FIG. **6** to FIG. **11** are the cross-sectional views corresponding to FIG. **3**. It should be understood that the method of manufacturing the semiconductor device described below is an example, and the semiconductor device can be manufactured by any other methods including modified examples of this embodiment within the scope of the appended claims.

(71) First, the n.sup.-type semiconductor substrate **10** implementing the n.sup.-type drift layer **1** illustrated in FIG. **2** is prepared. Next, a photolithography step and an ion implantation step are repeatedly executed so as to activate impurity ions implanted to the semiconductor substrate **10** by annealing. These steps provide the n-type accumulation layer **2**, the p.sup.-type base region **3**, the n.sup.+type emitter region **4**, and the p.sup.+type contact region **5** (refer to FIG. **1**) at the upper part of the semiconductor substrate **10** in the transistor part **101**, as illustrated in FIG. **1** and FIG. **2**. Similarly, the n-type accumulation layer **2** and the p.sup.-type anode region **13** are formed at the upper part of the semiconductor substrate **10** in the diode part **102**.

(72) The emitter region **4**, the contact region **5**, the base region **3**, the anode region **13**, the accumulation layer **2**, and the drift layer **1** are then partly and selectively removed from the top surface side of the semiconductor substrate **10** by photolithography and dry etching. The plural trenches **11** are thus formed at the upper part of the semiconductor substrate **10**, as illustrated in FIG. **4**.

(73) Next, the gate insulating film **6** is formed on the bottom surfaces and the side surfaces of the trenches **11** and the respective top surfaces of the emitter region **4**, the contact region **5**, and the anode region **13** by a thermal oxidation method or a chemical vapor deposition (CVD) method, for example. A polysilicon film (a doped polysilicon film) with which impurity ions such as phosphorus (P) or boron (B) are heavily doped is deposited so as to fill the inside of the respective trenches **11** via the gate insulating film **6** by the CVD method and the like. The polysilicon film and the gate insulating film **6** on the semiconductor substrate **10** are then selectively removed by photolithography and dry etching. The insulated gate electrode structure (**6**, **7**) composed of the gate insulating film **6** and the gate electrode **7** of the polysilicon film is thus formed in the respective trenches **11**, as illustrated in FIG. **5**.

(74) Next, a photoresist film is applied on the respective top surfaces of the insulated gate electrode structures (**6**, **7**), the emitter region **4**, the contact region **5**, and the anode region **13**, and is then delineated by photolithography. Using the delineated photoresist film as a mask for etching, the emitter region **4** and the respective insulated gate electrode structures (**6**, **7**) are partly and selectively removed by dry etching. These steps provide the projection **4a** at the upper part of the emitter region **4**, as illustrated in FIG. **6**. The similar projection is also formed at the upper part of the contact region **5** in the transistor part **101** and at the upper part of the anode region **13** in the diode part **102** illustrated in FIG. **1**. The height **h2** of the projection **4a** is greater than the height **h1** of the projection **4a** illustrated in FIG. **3**.

(75) Next, the first insulating film **21** that is a HTO film and the second insulating film **22** that is a BPSG film are sequentially formed by the CVD method and the like on the respective top surfaces of the insulated gate electrode structures (**6**, **7**), the emitter region **4**, the contact region **5**, and the anode region **13**. The interlayer insulating film **20** including the first insulating film **21** and the

second insulating film 22 is thus formed, as illustrated in FIG. 7. The first insulating film 21 and the second insulating film 22 respectively have a step 21a and a step 22a each corresponding to the projection 4a. The top surface of the second insulating film 22 may be flattened by a reflow after the deposition of the second insulating film 22. The top surface of the projection 4a is located at a higher position than the bottom surface of the interlayer insulating film 20.

(76) Next, a photoresist film is applied on the top surface of the interlayer insulating film 20, and is then delineated by photolithography. Using the delineated photoresist film as a mask for etching, the interlayer insulating film 20 is partly and selectively removed by dry etching, so as to open the contact hole 20a to which the top surface of the projection 4a is exposed, as illustrated in FIG. 8. The width of the contact hole 20a substantially conforms to the width w1 of the top surface of the projection 4a. The top surface of the projection 4a is entirely exposed, while the top surface of the flat part of the emitter region 4 other than the projection 4a in the mesa part is not exposed but is covered with the interlayer insulating film 20.

(77) After the contact hole 20a is opened, p-type impurity ions such as boron (B) or boron fluoride (BF.sub.2) may be selectively implanted to the projection of the contact region 5 illustrated in FIG. 1 and then subjected to annealing to activate the p-type impurity ions, so as to facilitate the extraction of the hole.

(78) Next, a native oxide film at the bottom of the contact hole 20a is removed by use of hydrofluoric acid (HF) or the like. A titanium film 34 is then deposited on the top surface of the projection 4a, the side surface of the contact hole 20a, and the top surface of the second insulating film 22 by sputtering or vapor deposition, for example, as illustrated in FIG. 9. The titanium film 34 has a thickness set in a range of about 20 nanometers or greater and 80 nanometers or less, for example.

(79) Next, titanium (Ti) of the titanium film 34 located at the bottom of the contact hole 20a and silicon (Si) of the projection 4a are led to react with each other by heat treatment such as rapid thermal annealing (RTA) so as to form the titanium silicide layer 31 at the bottom of the contact hole 20a, as illustrated in FIG. 10. The volume of the projection 4a is decreased and the height h1 of the projection 4a is thus decreased upon the formation of the titanium silicide layer 31.

However, since a part of the projection 4a remains, and the top surface of the projection 4a and the bottom surface 31a of the titanium silicide layer 31 are each located at a higher position than the bottom surface 20b of the interlayer insulating film 20, eaves (overhangs) can be prevented from being formed at the edge part of the first insulating film 21.

(80) While FIG. 10 illustrates the case in which the titanium film 34 located at the bottom of the contact hole 20a is all silicided, an unreacted part of the titanium film 34 located at the bottom of the contact hole 20a may remain on the top surface side of the titanium silicide layer 31.

(81) Next, the titanium film 34 located on the top surface of the second insulating film 22 and the side surface of the contact hole 20a is removed by wet etching and the like. The unreacted titanium film 34, when remains at the bottom of the contact hole 20a, is also removed. These steps thus remove all of the titanium film 34.

(82) Next, the titanium nitride film 32 is formed on the top surface of the titanium silicide layer 31, the side surface of the contact hole 20a, and the top surface of the second insulating film 22 by sputtering or vapor deposition, for example. The tungsten film 33 is further formed to fill the contact hole 20a via the titanium nitride film 32 by the CVD method and the like, as illustrated in FIG. 11. The titanium nitride film 32 and the tungsten film 33 located on the top surface of the second insulating film 22 are then selectively removed by dry etching, for example. These steps provide the connection conductor 30 including the titanium silicide layer 31, the titanium nitride film 32, and the tungsten film 33. The titanium nitride film 32 and the tungsten film 33 located on the top surface of the second insulating film 22 may be allowed to remain without being removed.

(83) Next, the front-surface electrode 40 is deposited on the respective top surfaces of the connection conductor 30 and the second insulating film 22 by sputtering or vapor deposition, for

example, as illustrated in FIG. 3. Next, the semiconductor substrate **10** is ground from the bottom surface side by chemical mechanical polishing (CMP), for example, so that the thickness of the semiconductor substrate **10** is adjusted to conform to that of a final product.

(84) Next, n-type impurity ions are implanted sequentially to different depths across the entire bottom surface of the semiconductor substrate **10**. The impurity ions are then activated by annealing so as to form the n-type buffer layer **8** and the n.sup.+-type cathode region **12** at the lower part of the semiconductor substrate **10**. Next, a mask for ion implantation is formed by photolithography, and p-type impurity ions are implanted to the transistor part **101**. The impurity ions are then activated by annealing to invert the conductivity type of the cathode region **12** in the transistor part **101** so as to form the p.sup.+-type collector region **9**.

(85) Next, as illustrated in FIG. 12, a particle beam of helium (He), for example, is radiated from the top surface side of the semiconductor substrate **10** so as to uniformly form the life-time control region **60** inside the drift layer **1**. Instead of the use of the particle beam of helium (He), a particle beam of proton (P) or an electron beam may be radiated. The particle beam may be radiated not from the top surface side but from the bottom surface side. Alternatively, a photoresist film may be delineated by photolithography to be used as a shielding film so that the life-time control region **60** is locally formed.

(86) Next, heat treatment (annealing) is executed. The annealing may be executed under an atmosphere containing hydrogen. The annealing regulates the formation of crystal defects of the life-time control region **60** so as to ensure an intended life time. While the radiation of the particle beam illustrated in FIG. 12 leads the gate insulating film **6** to be damaged to cause a dangling bond at the interface between the semiconductor substrate **10** and the gate insulating film **6** to lead to a decrease in a gate threshold, the hydrogen contained in the atmosphere or in the semiconductor substrate **10** reaches the gate insulating film **6** during the annealing to terminate the dangling bond, so as to avoid a decrease in the gate threshold. At this point, the hydrogen during the annealing can sufficiently reach the gate insulating film **6** without being absorbed to the titanium film **34**, since the titanium film **34** not reacted has been removed after the formation of the titanium silicide layer **31**.

(87) The hydrogen can also sufficiently reach the gate insulating film **6** without being absorbed to the titanium film **34** in the other steps of using the hydrogen other than the annealing after the radiation of the particle beam such as the step of forming the tungsten film **33**. In addition, a decrease in the gate threshold caused by the damage to the gate insulating film **6** during the formation of the contact hole **20a**, for example, can be avoided also in a heating step other than the annealing after the radiation of the particle beam.

(88) Thereafter, the rear-surface electrode **50** including gold (Au) is formed on the entire bottom surface of the semiconductor substrate **10** by sputtering or vapor deposition, for example. The semiconductor device according to the first embodiment is thus completed by the method as described above.

Comparative Example

(89) A method of manufacturing a semiconductor device of a comparative example is described below with reference to FIG. 13 to FIG. 17. The method of manufacturing the semiconductor device of the comparative example includes the same procedure as the method of manufacturing the semiconductor device according to the first embodiment by the step of forming the insulated gate electrode structures (**6**, **7**) illustrated in FIG. 5.

(90) Next, the first insulating film **21** and the second insulating film **22** are sequentially deposited to form the interlayer insulating film **20** on the respective top surfaces of the insulated gate electrode structures (**6**, **7**) and the emitter region **4** by the CVD method, for example, without the projection formed in the mesa part interposed between the trenches **11** adjacent to each other, as illustrated in FIG. 13.

(91) Next, as illustrated in FIG. 14, the contact hole **20a** is opened in the interlayer insulating film

20 by photolithography and dry etching so as to expose a part of the emitter region **4** to the contact hole **20a**. While FIG. **14** illustrates the case in which the bottom surface of the contact hole **20a** hollows out the upper part of the emitter region **4**, the etching may be stopped immediately at the point of exposing the top surface of the emitter region **4**.

(92) Next, as illustrated in FIG. **15**, the titanium film **34** is deposited on the bottom surface and the side surface of the contact hole **20a** and the top surface of the second insulating film **22** by the CVD method, for example. The titanium film **34** located at the bottom of the contact hole **20a** is then subjected to silicidation so as to form the titanium silicide layer **31**, as illustrated in FIG. **16**. At this point, the volume of the emitter region **4** is decreased and the lower part of the first insulating film **21** is hollowed out, causing eaves (overhangs) **20c** and **20d** at the edge part of the first insulating film **21**.

(93) Next, as illustrated in FIG. **17**, the titanium nitride film **32** is deposited on the top surface of the titanium silicide layer **31**, the side surface of the contact hole **20a**, and the top surface of the second insulating film **22** by the CVD method, for example. However, the presence of the eaves **20c** and **20d** at the first insulating film **21** causes voids in the titanium nitride film **32** at the positions provided with the eaves **20c** and **20d**, which impedes the formation of the intended titanium nitride film **32**.

(94) The subsequent formation of the tungsten film cannot be made appropriately at the positions of the voids in the titanium nitride film **32** if the tungsten film is deposited to fill the contact hole **20a** via the titanium nitride film **32** by the CVD method, for example. The inappropriate formation of the tungsten film may cause tungsten (W) of the tungsten film to spread toward silicon (Si) in the mesa part.

(95) Even if the titanium film **34** is subjected to silicidation after the titanium film **34** and the titanium nitride film **32** are sequentially deposited so as to form the titanium silicide film **31**, the titanium nitride film **32** may be partly dragged in association with the decrease in the volume of the emitter region **4** upon the formation of the titanium silicide layer **31**, causing a void in the titanium nitride film **32** accordingly.

(96) In contrast to the method of manufacturing the semiconductor device of the comparative example, the method of manufacturing the semiconductor device according to the first embodiment forms the projection **4a** at the upper part of the emitter region **4** provided in the mesa part interposed between the trenches **11** adjacent to each other, as illustrated in FIG. **6**. This leads the bottom surface **31a** of the titanium silicide layer **31** to be located at the higher position than the bottom surface **20b** of the interlayer insulating film **20** upon the formation of the titanium silicide layer **31**, as illustrated in FIG. **10**, so as to prevent the eaves from being caused in the first insulating film **21**. The manufacturing method according to the first embodiment thus can form the titanium nitride film **32** favorably after the formation of the titanium silicide layer **31**, and further form the tungsten film **33** favorably on the titanium nitride film **32**, so as to avoid the spread of tungsten (W) of the tungsten film **33** toward silicon (Si) in the mesa part.

First Modified Example

(97) A method of manufacturing a semiconductor device according to a first modified example of the first embodiment differs from the method of manufacturing the semiconductor device according to the first embodiment in selectively removing only a part of the upper part of the emitter region **4** without removing the gate insulating film **6** or the gate electrode **7** when forming the projection **4a** at the upper part of the emitter region **4**, as illustrated in FIG. **18**. The other steps of the method of manufacturing the semiconductor device according to the first modified example of the first embodiment are the same as those of the method of manufacturing the semiconductor device according to the first embodiment.

(98) The first modified example of the first embodiment, which selectively removes only a part of the upper part of the emitter region **4** without removing the gate insulating film **6** or the gate electrode **7** when forming the projection **4a** at the upper part of the emitter region **4**, can form the

titanium nitride film **32** and the tungsten film **33** favorably as in the case of the first embodiment.

Second Modified Example

(99) A method of manufacturing a semiconductor device according to a second modified example of the first embodiment differs from the method of manufacturing the semiconductor device according to the first embodiment in sequentially forming the titanium film **34** and the titanium nitride film **32** before forming the titanium silicide layer **31**, as illustrated in FIG. **19**. The titanium film **34** located at the bottom of the contact hole **20a** is subjected to silicidation after sequentially forming the titanium film **34** and the titanium nitride film **32** so as to form the titanium silicide layer **31**. The other steps of the method of manufacturing the semiconductor device according to the second modified example of the first embodiment are the same as those of the method of manufacturing the semiconductor device according to the first embodiment.

(100) This manufacturing method thus forms the connection conductor **30** including the titanium silicide layer **31**, the titanium film **34**, the titanium nitride film **32**, and the tungsten film **33**, as illustrated in FIG. **20**. The titanium film **34** is interposed between the titanium silicide layer **31** and the titanium nitride film **32** so as to be in contact with the titanium silicide layer **31** and the titanium nitride film **32**.

(101) While FIG. **20** illustrates the case in which the titanium film **34** located on the top surface of the titanium silicide layer **31** is not all silicided but partly remains, all of the titanium film **34** located on the top surface of the titanium silicide layer **31** may be silicided completely. In such a case, the top surface of the titanium silicide layer **31** is in contact with the titanium nitride film **32**, while the titanium film **34** remains on the side surface of the contact hole **20a**. The titanium film **34** and the titanium nitride film **32** on the interlayer insulating film **20** are not necessarily removed.

(102) The method of manufacturing the semiconductor device according to the second modified example of the first embodiment, which sequentially forms the titanium film **34** and the titanium nitride film **32** before forming the titanium silicide layer **31**, can prevent the titanium nitride film **32** from being greatly dragged downward upon the formation of the titanium silicide layer **31** since the projection **4a** is preliminarily formed, so as to avoid breakage of the titanium nitride film **32**. The second modified example thus can form the titanium nitride film **32** and the tungsten film **33** favorably as in the case of the first embodiment.

Third Modified Example

(103) A method of manufacturing a semiconductor device according to a third modified example of the first embodiment differs from the method of manufacturing the semiconductor device according to the first embodiment in defining the width $w3$ of the bottom surface of the contact hole **20a** of the interlayer insulating film **20** to be greater than the width $w1$ of the projection **4a** when opening the contact hole **20a**, as illustrated in FIG. **21**. The level of the bottom surface of the contact hole **20a** conforms to the level of the top surface of the projection **4a**. The other steps of the method of manufacturing the semiconductor device according to the third modified example of the first embodiment are the same as those of the method of manufacturing the semiconductor device according to the first embodiment. The width $w3$ of the titanium nitride film **32** located at the bottom of the contact hole **20a** is thus greater than the width $w1$ of the titanium silicide layer **31**, as illustrated in FIG. **22**.

(104) The method of manufacturing the semiconductor device according to the third modified example of the first embodiment, which defines the width $w3$ of the bottom surface of the contact hole **20a** to be greater than the width $w1$ of the projection **4a**, can facilitate the exposure of the entire top surface of the projection **4a** if the accuracy of the positioning of the contact hole **20a** is low, for example. The third modified example thus can form the titanium nitride film **32** and the tungsten film **33** favorably as in the case of the first embodiment.

Fourth Modified Example

(105) A method of manufacturing a semiconductor device according to a fourth modified example of the first embodiment evens out the top surface of the first insulating film **21** by etching back or

grinding, for example, after depositing the first insulating film **21**, and then deposits the second insulating film **22** on the first insulating film **21**, as illustrated in FIG. **23**. While FIG. **23** illustrates the case in which the step **21a** of the first insulating film **21** remains, the step **21a** may be removed completely. Alternatively, the top surface of the first insulating film **21** may be further removed so as to lead the level of the top surface of the first insulating film **21** to substantially conform to the level of the top surface of the projection **4a**. The position of the boundary between the first insulating film **21** and the second insulating film **22** may be led to approximate to the level of the top surface of the projection **4a** when the second insulating film **22** is deposited so as to substantially conform to the level of the top surface of the projection **4a**.

(106) Next, as illustrated in FIG. **24**, the contact hole **20a** is opened in the interlayer insulating film **20** by the CVD method, for example. FIG. **24** illustrates the case in which the position of the contact hole **20a** is displaced so as to be provided with an under-etched part on the top surface of the projection **4a**. The top surface of the projection **4a** is not completely exposed but is partly covered by the interlayer insulating film **20**.

(107) Next, as illustrated in FIG. **25**, a native oxide film on the mesa part is removed by hydrofluoric acid (HF). The top surface of the projection **4a** can be exposed completely at this point by use of a difference of etch selectivity between the first insulating film **21** that is a HTO film and the HF of the second insulating film **22** that is a BPSG film, and by use of the spread of the etching in the lateral direction that is greater in the BPSG film than in the HTO film.

(108) The method of manufacturing the semiconductor device according to the fourth modified example of the first embodiment can expose all of the top surface of the projection **4a** by the removal of the native oxide film if the top surface of the projection **4a** is not exposed completely when the contact hole **20a** is opened, so as to form the titanium nitride film **32** and the tungsten film **33** favorably as in the case of the first embodiment. The manufacturing method according to the fourth modified example first evens out the top surface of the first insulating film **21** after being deposited and then deposits the second insulating film **22** on the first insulating film **21**, so as to facilitate the exposure of the top surface of the projection **4a**. The manufacturing method also forms the projection **4a** to be higher than the maximum displaced width at the position of the contact hole **20a**, so as to prevent the flat part other than the projection **4a** in the mesa part from being exposed or dug downward.

Fifth Modified Example

(109) A semiconductor device according to a fifth modified example of the first embodiment differs from the semiconductor device according to the first embodiment in that the n.sup.+-type emitter region **4** and the p.sup.+-type contact region **5** in the mesa part interposed between the trenches **11** adjacent to each other are aligned in the arranged direction of the plural trenches **11**, as illustrated in FIG. **26**. The emitter region **4** and the contact region **5** may each have a straight (stripe-shaped) part extending parallel to the extending direction of the respective trenches **11** in the planar pattern. The other configurations of the semiconductor device according to the fifth modified example of the first embodiment are the same as those of the semiconductor device according to the first embodiment, and overlapping explanations are not repeated below.

(110) The semiconductor device according to the fifth modified example of the first embodiment, in which the n.sup.+-type emitter region **4** and the p.sup.+-type contact region **5** in the mesa part interposed between the trenches **11** adjacent to each other are aligned in the arranged direction of the trenches **11**, can also form the titanium nitride film **32** and the tungsten film **33** favorably as in the case of the first embodiment.

Second Embodiment

(111) <Configuration of Semiconductor Device>

(112) A fundamental configuration of a semiconductor device according to a second embodiment is substantially the same as that of the semiconductor device according to the first embodiment illustrated in FIG. **1** and FIG. **2**. FIG. **27** is a cross-sectional view illustrating the semiconductor

device according to the second embodiment corresponding to the cross section of the semiconductor device according to the first embodiment illustrated in FIG. 3. As illustrated in FIG. 27, the semiconductor device according to the second embodiment differs from the semiconductor device according to the first embodiment in the structure around the connection conductor 30.

(113) As illustrated in FIG. 27, the emitter region 4 is provided in the mesa part interposed between the trenches 11 adjacent to each other. The emitter region 4 is not provided with the projection at the upper part. The bottom surface of the contact hole 20a has a shape convex toward the upper part of the emitter region 4. The bottom surface of the contact hole 20a may conform to the top surface of the emitter region 4.

(114) The connection conductor 30 is buried in the contact hole 20a. The connection conductor 30 includes a silicon film 35 including silicon (Si) such as polysilicon with which p-type impurity ions or n-type impurity ions are heavily doped, the titanium silicide layer 31 that is a silicide layer including titanium silicide (TiSi_{sub}.2), the titanium nitride film 32 that is a barrier metal film including titanium nitride (TiN), and the tungsten film 33 that is a metal film including tungsten (W).

(115) The silicon film 35 has a thickness set in a range of about 10 nanometers or greater and 80 nanometers or less, for example. The titanium silicide layer 31 has a thickness set in a range of about 20 nanometers or greater and 80 nanometers or less, for example. The titanium nitride film 32 has a thickness set in a range of about 20 nanometers or greater and 140 nanometers or less, for example. The tungsten film 33 has a thickness set in a range of about 100 nanometers or greater and 1500 nanometers or less, for example.

(116) The silicon film 35 is provided to cover the bottom surface and the side surface of the contact hole 20a. The silicon film 35 is in contact with the emitter region 4 located at the bottom of the contact hole 20a, and is in contact with the respective side surfaces of the first insulating film 21 and the second insulating film 22 exposed on the side surface of the contact hole 20a.

(117) The titanium silicide layer 31 is provided to cover the bottom surface and the side surface of the contact hole 20a via the silicon film 35. The titanium silicide layer 31 is in contact with the silicon film 35. The lowermost part of the bottom surface (the bottom) 31a of the titanium silicide layer 31 is located at a higher position than the bottom surface 20b of the interlayer insulating film 20.

(118) The titanium nitride film 32 is provided to cover the bottom surface and the side surface of the contact hole 20a via the silicon film 35 and the titanium silicide layer 31. The titanium nitride film 32 is in contact with the titanium silicide layer 31.

(119) The tungsten film 33 is deposited in the contact hole 20a via the silicon film 35, the titanium silicide layer 31, and the titanium nitride film 32 so as to fill the contact hole 20a. The tungsten film 33 is in contact with the titanium nitride film 32. The other configurations of the semiconductor device according to the second embodiment are substantially the same as those of the semiconductor device according to the first embodiment, and overlapping explanations are not repeated below.

(120) <Method of Manufacturing Semiconductor Device>

(121) An example of a method of manufacturing the semiconductor device according to the second embodiment is described below with reference to FIG. 28 to FIG. 30. FIG. 28 to FIG. 30 are cross-sectional views each corresponding to FIG. 27. It should be understood that the method of manufacturing the semiconductor device described below is an example, and the semiconductor device can be manufactured by any other methods including modified examples of this embodiment within the scope of the appended claims.

(122) The method of manufacturing the semiconductor device according to the second embodiment includes the same procedure as the method of manufacturing the semiconductor device according to the first embodiment by the step of forming the insulated gate electrode structures (6, 7) illustrated in FIG. 5. Next, the first insulating film 21 and the second insulating film 22 are

sequentially deposited on the top surfaces of the respective insulated gate electrode structures (6, 7) and the emitter region 4 so as to form the interlayer insulating film 20 by the CVD method, for example, without the projection formed in the mesa part interposed between the trenches 11 adjacent to each other, as illustrated in FIG. 13.

(123) Next, as illustrated in FIG. 14, the contact hole 20a is opened in the interlayer insulating film 20 by photolithography and dry etching so as to expose a part of the emitter region 4 to the contact hole 20a. While FIG. 14 illustrates the case in which the bottom surface of the contact hole 20a hollows out the upper part of the emitter region 4, the etching may be stopped immediately at the point of exposing the top surface of the emitter region 4.

(124) Next, as illustrated in FIG. 28, the silicon film 35 of polysilicon with which p-type impurity ions or n-type impurity ions are heavily doped, for example, is deposited on the bottom surface and the side surface of the contact hole 20a and the top surface of the second insulating film 22 by the CVD method and the like. The top surface of the silicon film 35 located at the bottom of the contact hole 20a is located at a higher position than the bottom surface of the interlayer insulating film 20. The silicon film 35 located on the top surface of the second insulating film 22 may be selectively removed so as to lead the silicon film 35 to remain only in the contact hole 20a.

(125) Next, the ion implantation and the annealing are executed so as to cause the part of the silicon film 35 in contact with the emitter region 4 to be an n-type region and cause the part of the silicon film 35 in contact with the contact region 5 to be a p-type region. For example, after the silicon film 35 with which the n-type impurity ions are heavily doped is deposited, p-type impurity ions such as boron (B) may be implanted and then activated by annealing to invert the conductivity type of the n-type region of the silicon film 35 in contact with the contact region 5 so as to selectively form the p-type region.

(126) Next, as illustrated in FIG. 29, the titanium film 34 is deposited by sputtering or vapor deposition, for example. Next, the titanium film 34 and a part of the silicon film 35 are led to react with each other by heat treatment so as to form the titanium silicide layer 31 on the top surface side of the silicon film 35, as illustrated in FIG. 30. The silicon film 35 is not completely silicided but partly remains. The silicon film 35 covers the bottom and the side surface of the contact hole 20a, so as to prevent overhangs from being formed in the first insulating film 21 upon the formation of the titanium silicide layer 31.

(127) While FIG. 30 illustrates the case in which the titanium film 34 is completely silicided, the titanium film 34 may be partly unreacted to remain. The unreacted titanium film 34 when remaining may be removed.

(128) Next, the titanium nitride film 32 is formed on the titanium silicide layer 31 by sputtering or vapor deposition, for example. The tungsten film 33 is further deposited on the titanium nitride film 32 by the CVD method and the like so as to fill the contact hole 20a. The titanium nitride film 32 and the tungsten film 33 located on the top surface of the second insulating film 22 are then selectively removed. These steps provide the connection conductor 30 in the contact hole 20a including the silicon film 35, the titanium silicide layer 31, the titanium nitride film 32, and the tungsten film 33.

(129) Next, as illustrated in FIG. 27, the front-surface electrode 40 is deposited on the top surface of the second insulating film 22 and the top surface of the connection conductor 30 by sputtering or vapor deposition, for example. The following steps are the same as those in the method of manufacturing the semiconductor device according to the first embodiment, and overlapping explanations are not repeated below. The semiconductor device according to the second embodiment is thus completed by the method described above.

(130) The method of manufacturing the semiconductor device according to the second embodiment deposits the silicon film 35 after opening the contact hole 20a as illustrated in FIG. 28. This can avoid the provision of eaves in the first insulating film 21 upon the formation of the titanium silicide layer 31, as illustrated in FIG. 29. The manufacturing method according to the second

embodiment thus can form the titanium nitride film **32** and the tungsten film **33** favorably after the formation of the titanium silicide layer **31**, so as to prevent a spread of tungsten (W) of the tungsten film **33** toward silicon (Si) in the mesa part.

(131) In addition, the method of manufacturing the semiconductor device according to the second embodiment, which removes the unreacted titanium film **34** after the formation of the titanium silicide layer **31**, can lead the hydrogen during the annealing to sufficiently reach the gate insulating film **6** without being absorbed to the titanium film **34**, as in the case of the method of manufacturing the semiconductor device according to the first embodiment.

(132) The method of manufacturing the semiconductor device according to the second embodiment may subject the titanium film **34** to silicidation to form the titanium silicide layer **31** after sequentially depositing the titanium film **34** and the titanium nitride film **32**, instead of the step of depositing the titanium nitride film **32** after subjecting the titanium film **34** to silicidation to form the titanium silicide layer **31**. This case can also prevent the titanium nitride film **32** from being greatly dragged downward upon the formation of the titanium silicide layer **31**, so as to avoid breakage of the titanium nitride film **32**.

(133) The method of manufacturing the semiconductor device according to the second embodiment may deposit the silicon film **35** to cover the top surface of the projection **4a** after forming the projection **4a** in the mesa part as illustrated in FIG. **6** and then opening the contact hole **20a** so as to expose the top surface of the projection **4a** as illustrated in FIG. **8** through the same steps as in the method of manufacturing the semiconductor device according to the first embodiment. This case can also form the titanium nitride film **32** and the tungsten film **33** favorably as in the case of the first embodiment.

Other Embodiments

(134) As described above, the invention has been described according to the first and second embodiments, but it should not be understood that the description and drawings implementing a portion of this disclosure limit the invention. Various alternative embodiments of the present invention, examples, and operational techniques will be apparent to those skilled in the art from this disclosure.

(135) While the first and second embodiments have been illustrated above with the semiconductor device that is the RC-IGBT, the present invention can also be applied to other IGBTs other than the RC-IGBT. The present invention can also be applied to a MOSFET using a drain region of n.sup.+ -type, instead of the p.sup.+ -type collector region **9** that is the IGBT in the transistor **10** illustrated in FIG. **2**.

(136) While the first and second embodiments have been illustrated above with the case of using the titanium silicide layer **31**, the present invention may be applied to a case of using a silicide layer including a compound of metal, such as nickel (Ni), tungsten (W), cobalt (Co), molybdenum (Mo), zinc (Zn), hafnium (Hf), platinum (Pt), palladium (Pd), iron (Fe), chromium (Cr), tantalum (Ta), and niobium (Nb), and silicon, instead of the titanium silicide layer **31**. In addition, the first and second embodiments have been illustrated above with the case of using the titanium nitride film **32** as a barrier metal film, the present invention may be applied to a case of using a barrier metal film of titanium-tungsten (TiW) or tantalum nitride (TaN), for example. Further, the first and second embodiments have been illustrated above with the case of using the tungsten film **33** as a buried metal film, the present invention may be applied to a case of using a metal film of aluminum (Al) or copper (Cu), for example, instead of the tungsten film **33**.

(137) The respective configurations disclosed in the first and second embodiments of the present invention and the respective modified examples can be combined together as necessary within a range without contradicting each other. As described above, the invention includes various embodiments of the present invention and the like not described herein. Therefore, the scope of the present invention is defined only by the technical features specifying the present invention, which

are prescribed by claims, the words and terms in the claims shall be reasonably construed from the subject matters recited in the present Specification.

Claims

1. A semiconductor device comprising: a semiconductor substrate; a plurality of trenches provided on a top surface side of the semiconductor substrate; an insulated gate electrode structure buried inside the respective trenches; an interlayer insulating film deposited on top surfaces of the semiconductor substrate and the insulated gate electrode structure; and a silicide layer deposited at a bottom of a contact hole penetrating the interlayer insulating film so as to be in contact with the top surface of the semiconductor substrate interposed between the trenches adjacent to each other, wherein at least a part of a bottom surface of the silicide layer is located at a higher position than a bottom surface of the interlayer insulating film.
2. The semiconductor device of claim 1, wherein the silicide layer is a titanium silicide layer.
3. The semiconductor device of claim 1, further comprising a life-time control region provided inside the semiconductor substrate.
4. The semiconductor device of claim 1, further comprising a titanium nitride film deposited on a top surface of the silicide layer and a side surface of the contact hole so as to be in contact with the top surface of the silicide layer.
5. The semiconductor device of claim 4, further comprising a tungsten film buried inside the contact hole via the titanium nitride film.
6. The semiconductor device of claim 1, wherein a width of the silicide layer is narrower than a width of a bottom surface of the contact hole.
7. The semiconductor device of claim 1, being a reverse-conducting insulated gate bipolar transistor comprising: a transistor part provided in a part of the semiconductor substrate; and a diode part provided in another part of the semiconductor substrate.
8. A method of manufacturing a semiconductor substrate, comprising: digging a plurality of trenches from a top surface side of a semiconductor substrate; burying an insulated gate electrode structure in the respective trenches; depositing an interlayer insulating film on top surfaces of the semiconductor substrate and the insulated gate electrode structure; forming a contact hole in the interlayer insulating film located on the semiconductor substrate interposed between the respective trenches; and forming a silicide layer inside the contact hole such that at least a part of a bottom surface of the silicide layer is located at a higher position than a bottom surface of the interlayer insulating film.
9. The method of manufacturing the semiconductor substrate of claim 8, wherein the silicide layer is a titanium silicide layer.
10. The method of manufacturing the semiconductor substrate of claim 8, wherein: the burying the insulated gate electrode structure comprises forming a projection at an upper part of the semiconductor substrate interposed between the trenches adjacent to each other; the forming the contact hole forms the contact hole such that an upper part of the projection is exposed to the contact hole; the forming the silicide layer forms the silicide layer by depositing a titanium film on a top surface of the projection and leading the titanium film and a part of the projection to react with each other by heat treatment so as to.
11. The method of manufacturing the semiconductor substrate of claim 10, wherein a width of a bottom surface of the contact hole is defined to be greater than a width of the projection.
12. The method of manufacturing the semiconductor substrate of claim 10, further comprising removing the titanium film not reacted after forming the silicide layer.
13. The method of manufacturing the semiconductor substrate of claim 10, wherein the forming the silicide layer deposits a titanium nitride film after depositing the titanium film and before forming the silicide layer.

14. The method of manufacturing the semiconductor substrate of claim 13, further comprising filling the contact hole with a tungsten film via the titanium nitride film after forming the titanium nitride film.

15. The method of manufacturing the semiconductor substrate of claim 14, further comprising radiating a particle beam toward the semiconductor substrate.

16. The method of manufacturing the semiconductor substrate of claim 15, further comprising executing annealing after radiating the particle beam.

17. The method of manufacturing the semiconductor substrate of claim 10, further comprising forming a titanium nitride film so as to be in contact with a top surface of the silicide layer after forming the silicide layer.

18. The method of manufacturing the semiconductor substrate of claim 8, wherein the forming the silicide layer comprises: depositing a silicon film and a titanium film inside the contact hole; and leading the titanium film and at least a part of the silicon film to react with each other by heat treatment so as to form the silicide layer.
