



US007554159B2

(12) **United States Patent**  
**Ker et al.**

(10) **Patent No.:** **US 7,554,159 B2**  
(45) **Date of Patent:** **Jun. 30, 2009**

(54) **ELECTROSTATIC DISCHARGE  
PROTECTION DEVICE AND METHOD OF  
MANUFACTURING THE SAME**

(76) Inventors: **Ming-Dou Ker**, Bldg. 51, 195, Chung Hsing Rd., Sec. 4, Chutung, Hsinchu (TW); **Tang-Kui Tseng**, Bldg. 51, 195, Chung Hsing Rd., Sec. 4, Chutung, Hsinchu (TW); **Hsin-Chin Jiang**, Bldg. 51, 195, Chung Hsing Rd., Sec. 4, Chutung, Hsinchu (TW); **Chyh-Yih Chang**, Bldg. 51, 195, Chung Hsing Rd., Sec. 4, Chutung, Hsinchu (TW); **Jeng-Jie Peng**, Bldg. 51, 195, Chung Hsing Rd., Sec. 4, Chutung, Hsinchu (TW)

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

(21) Appl. No.: **11/045,300**

(22) Filed: **Jan. 31, 2005**

(65) **Prior Publication Data**

US 2005/0127445 A1 Jun. 16, 2005

**Related U.S. Application Data**

(62) Division of application No. 10/230,055, filed on Aug. 29, 2002, now Pat. No. 6,882,009.

(51) **Int. Cl.**  
**H01L 23/62** (2006.01)

(52) **U.S. Cl.** ..... **257/360; 257/E21.633;**  
438/133; 361/220

(58) **Field of Classification Search** ..... 438/279,  
438/301, 303, 390, 133, 223, 224, 227, 228,  
438/275, 306, 307; 257/360–362, 400, 408,  
257/E21.633; 361/56, 90, 100, 101, 220

See application file for complete search history.

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

4,692,781 A	9/1987	Rountree et al.
5,400,202 A	3/1995	Metz et al.
5,452,171 A	9/1995	Metz et al.
5,510,279 A	4/1996	Chien et al.
5,517,051 A	5/1996	Chatterjee
5,572,394 A	11/1996	Ker et al.
5,576,574 A *	11/1996	Hong ..... 438/291
5,631,793 A	5/1997	Ker et al.
5,646,054 A *	7/1997	Rhee ..... 438/507
5,646,808 A	7/1997	Nakayama
5,698,884 A	12/1997	Dennen
5,734,541 A	3/1998	Iniewski et al.
5,740,000 A	4/1998	Stackhouse et al.
5,744,842 A	4/1998	Ker
5,747,834 A	5/1998	Chen et al.
5,763,919 A	6/1998	Lin
5,838,146 A	11/1998	Singer
5,982,600 A *	11/1999	Cheng ..... 361/111
6,147,383 A	11/2000	Kuroda

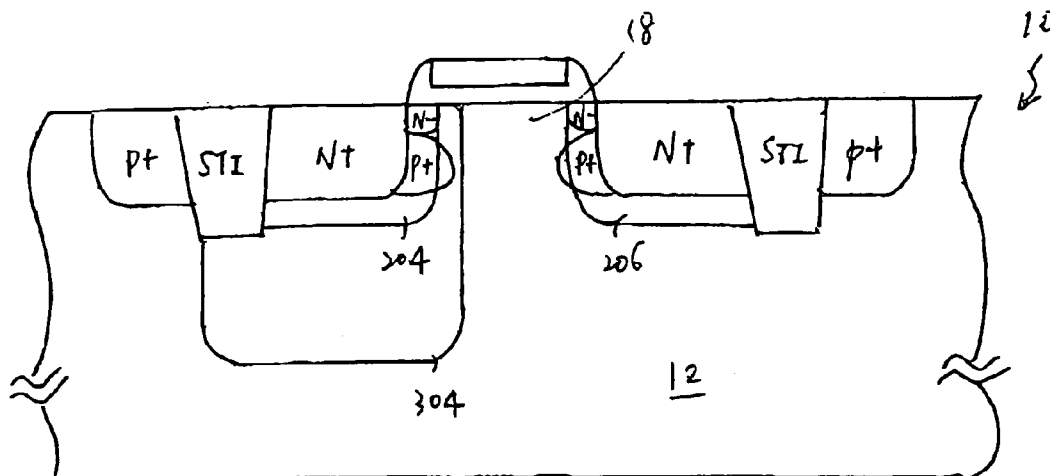
(Continued)

*Primary Examiner*—David Vu

(57) **ABSTRACT**

An electrostatic discharge protection device that includes a semiconductor substrate of a first dopant type, at least one source/drain pair of a second dopant type formed in the substrate, wherein the source/drain pair is separated to define a channel region therebetween, a lightly-doped region of the first dopant type defined between the source/drain pair and including at least a portion of the channel region, a gate dielectric layer formed over the substrate, and a gate formed over the gate dielectric layer and above the channel region.

**24 Claims, 14 Drawing Sheets**



## Page 2

U.S. PATENT DOCUMENTS				6,426,291 B1	7/2002	Hu et al.
6,147,538 A	11/2000	Andresen et al.		6,465,311 B2	10/2002	Shenoy
6,211,023 B1 *	4/2001	Yeh et al. ....	438/299	6,528,850 B1	3/2003	Hebert
6,239,472 B1	5/2001	Shenoy		6,546,522 B1 *	4/2003	Chen ..... 716/2
6,256,184 B1	7/2001	Gauthier, Jr. et al.		6,671,153 B1	12/2003	Ker et al.
6,362,062 B1 *	3/2002	Nandakumar .....	438/303	6,822,297 B2 *	11/2004	Nandakumar et al. .... 257/356
				* cited by examiner		

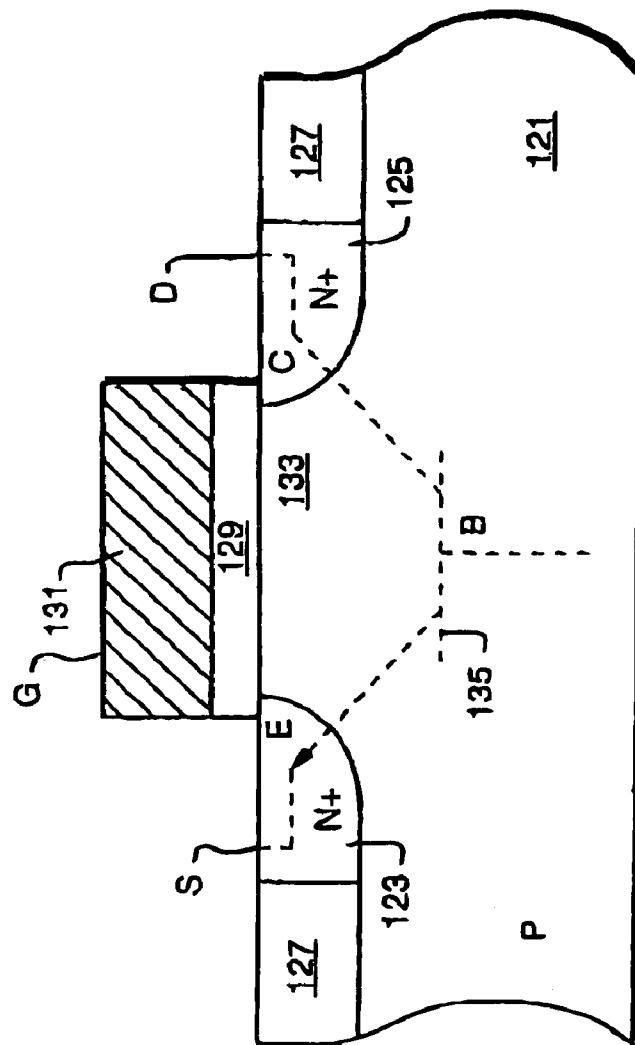
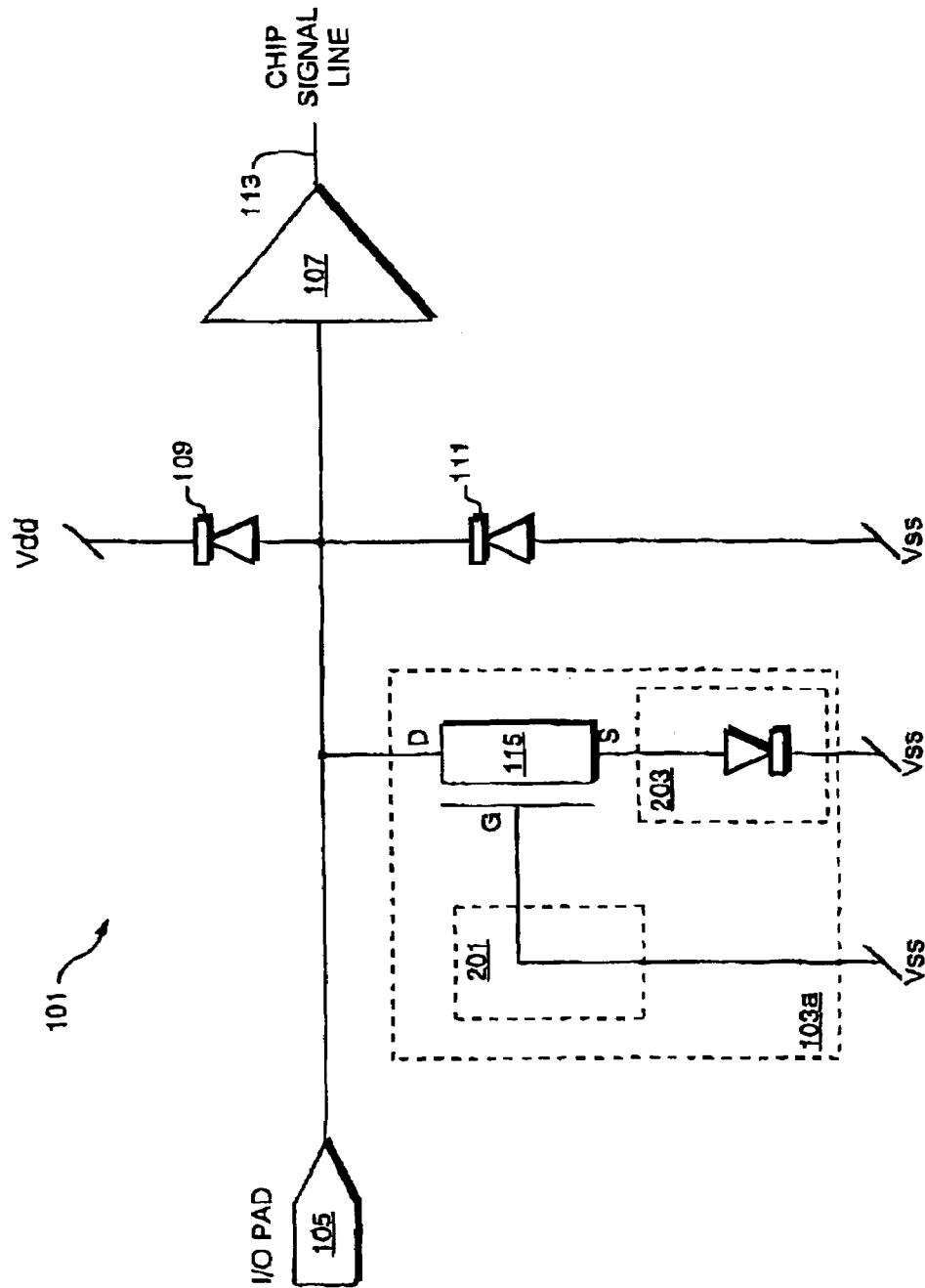


FIG. 1 PRIOR ART



*PRIOR ART*

FIG. 2

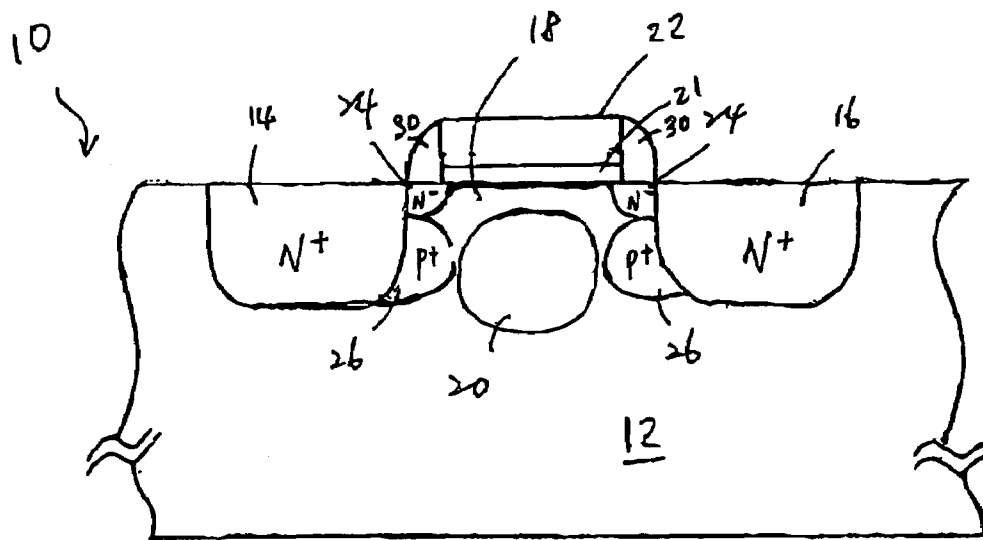


FIG. 3

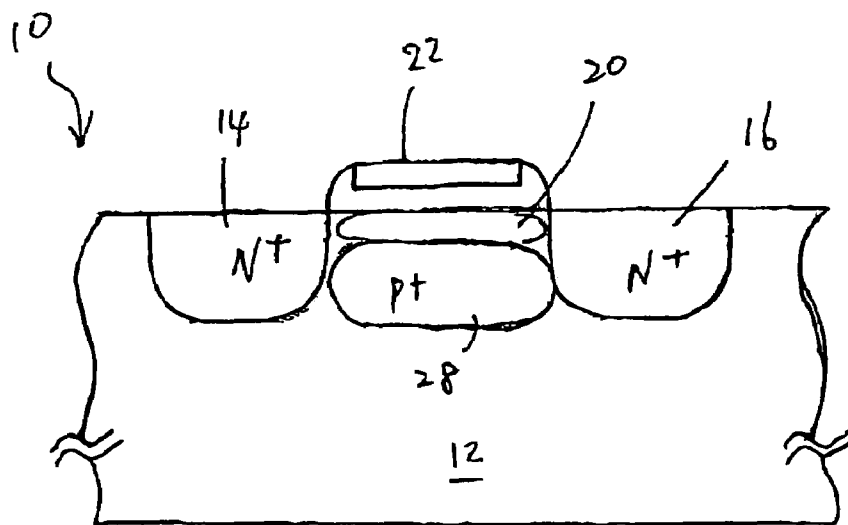


FIG. 4

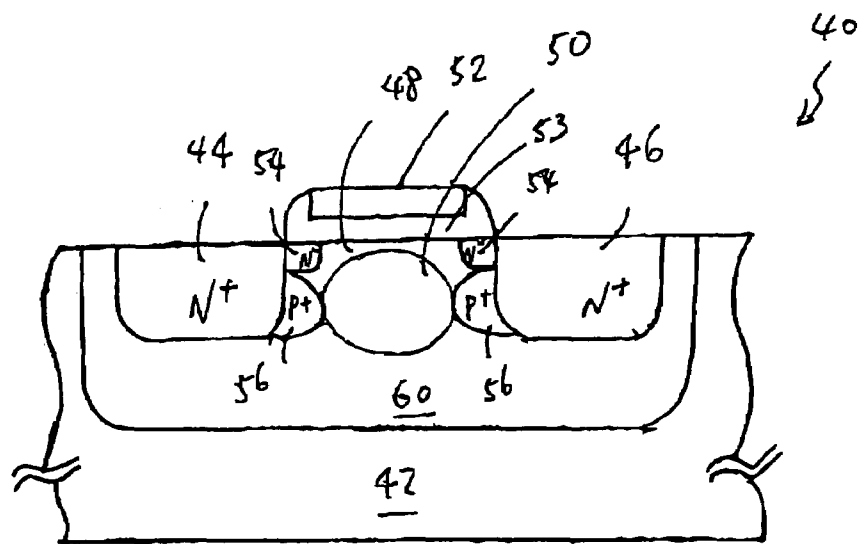


FIG. 5

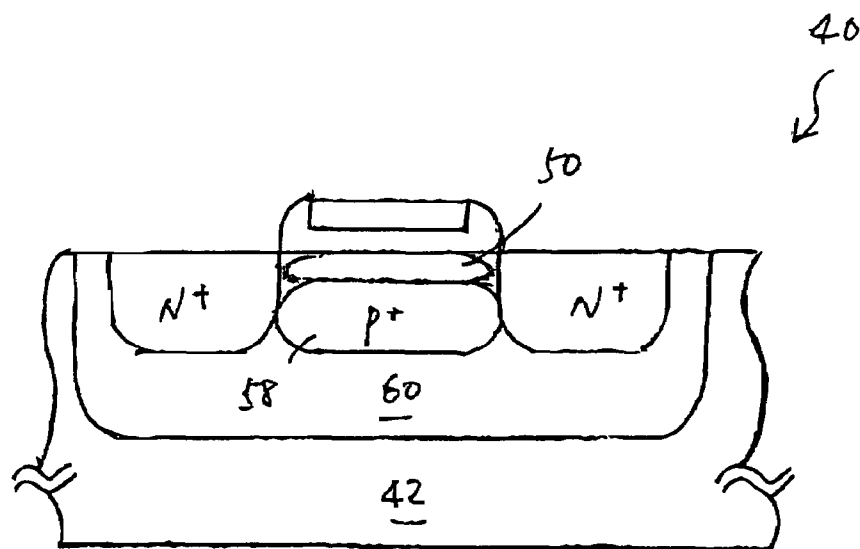


FIG. 6

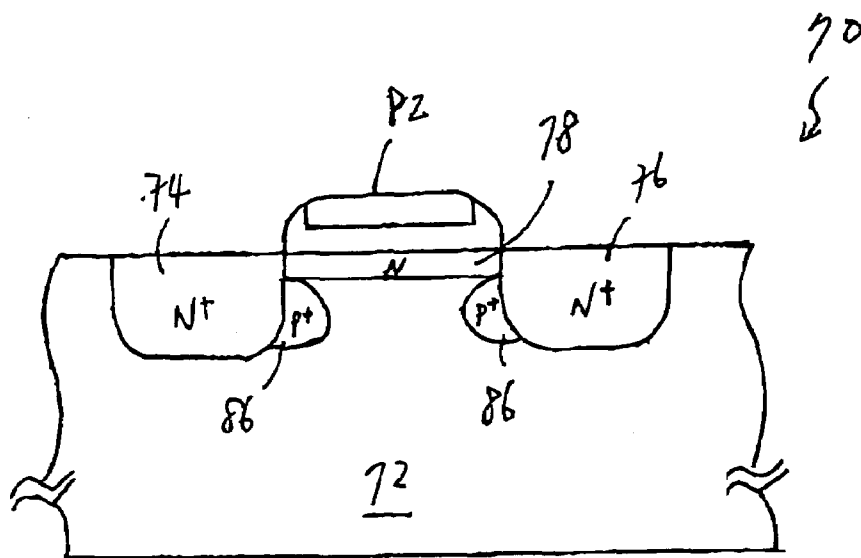


FIG. 7

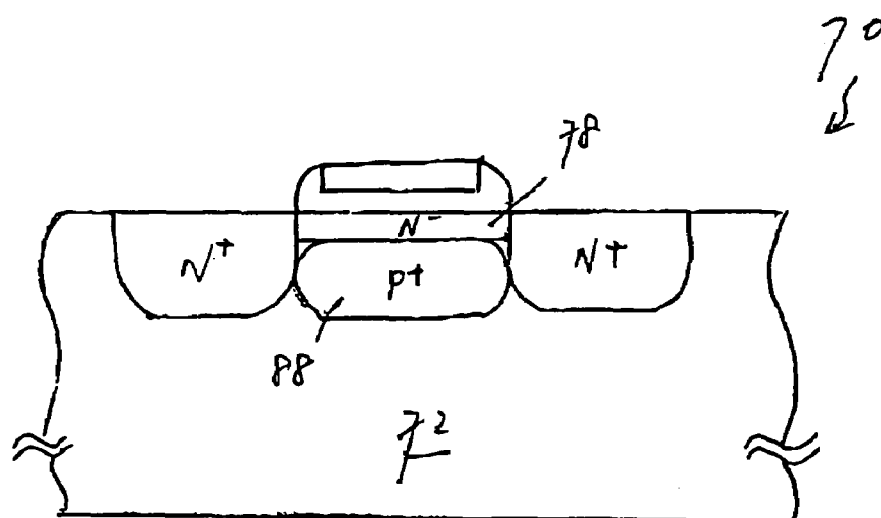


FIG. 8

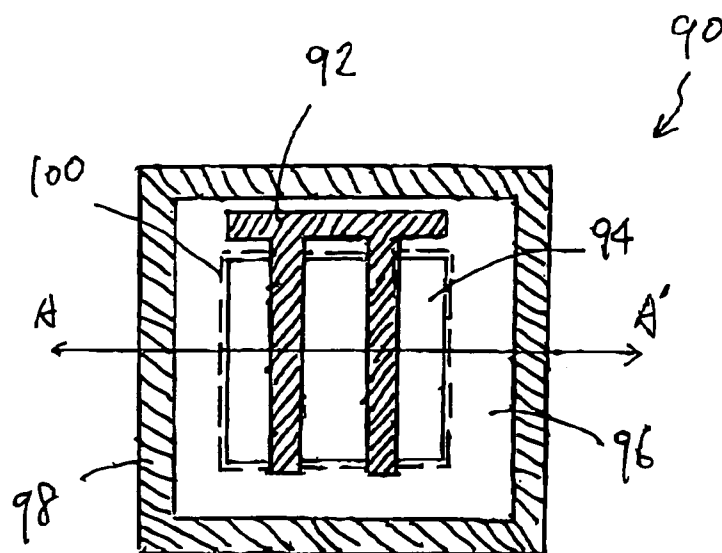


FIG. 9

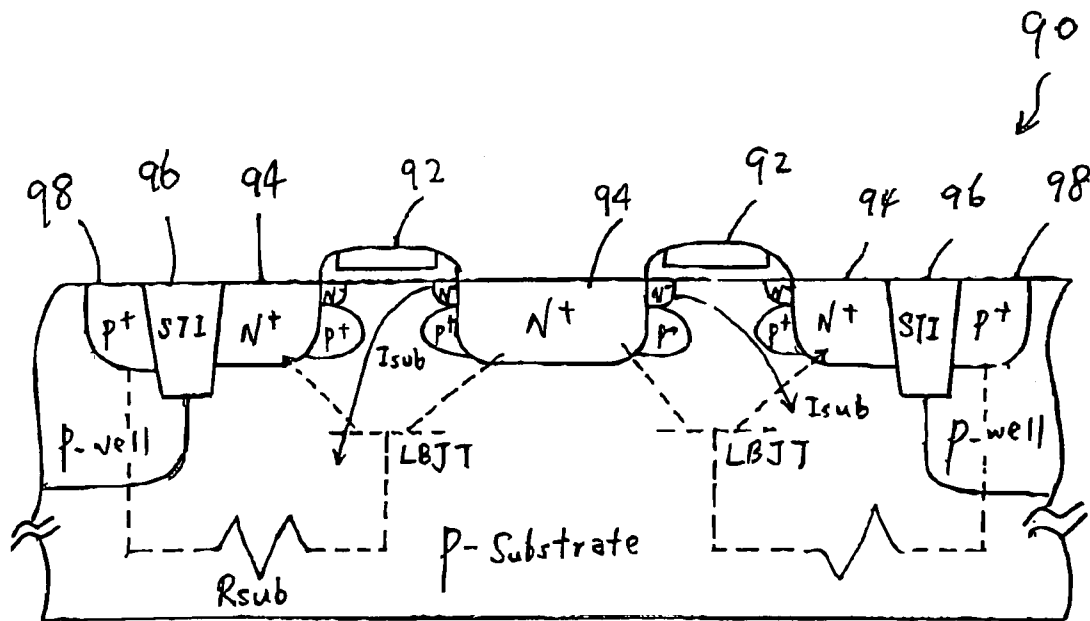


FIG. 10



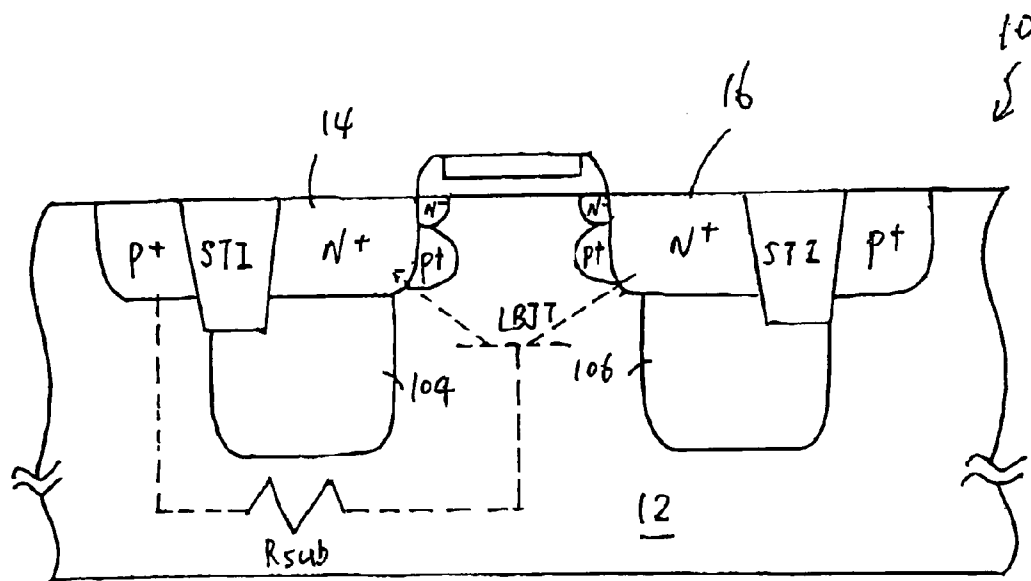


FIG. 11

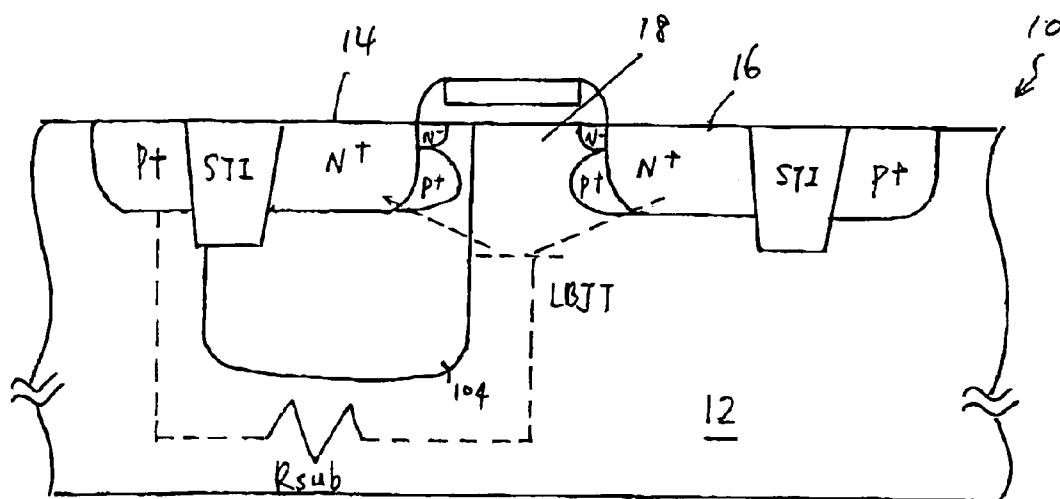


FIG. 12

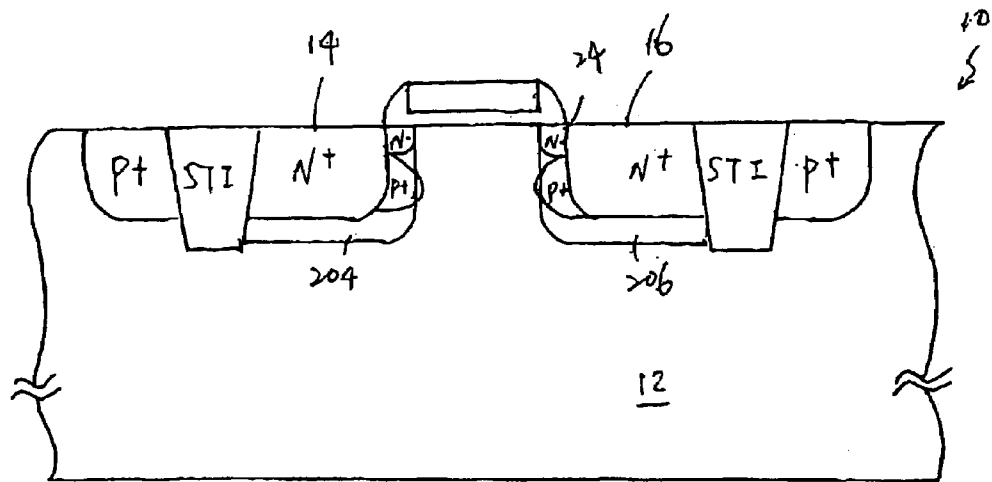


FIG. 13

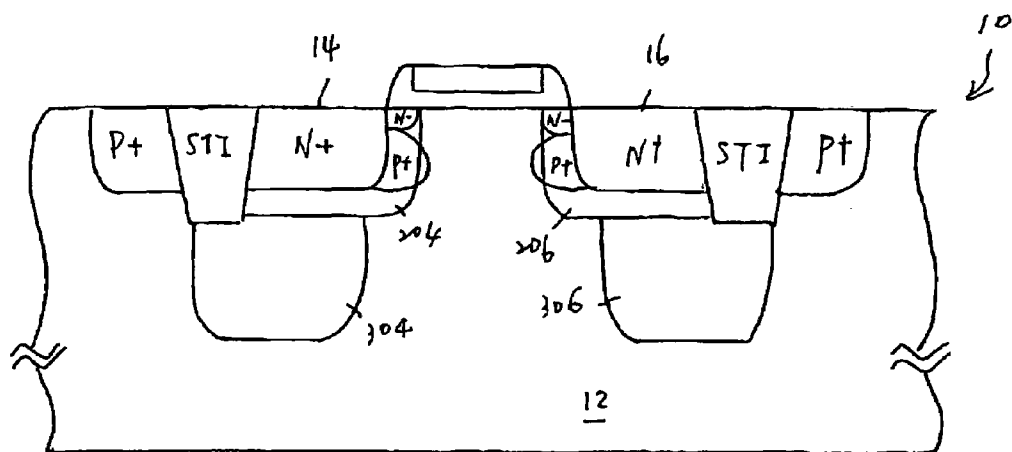


FIG. 14

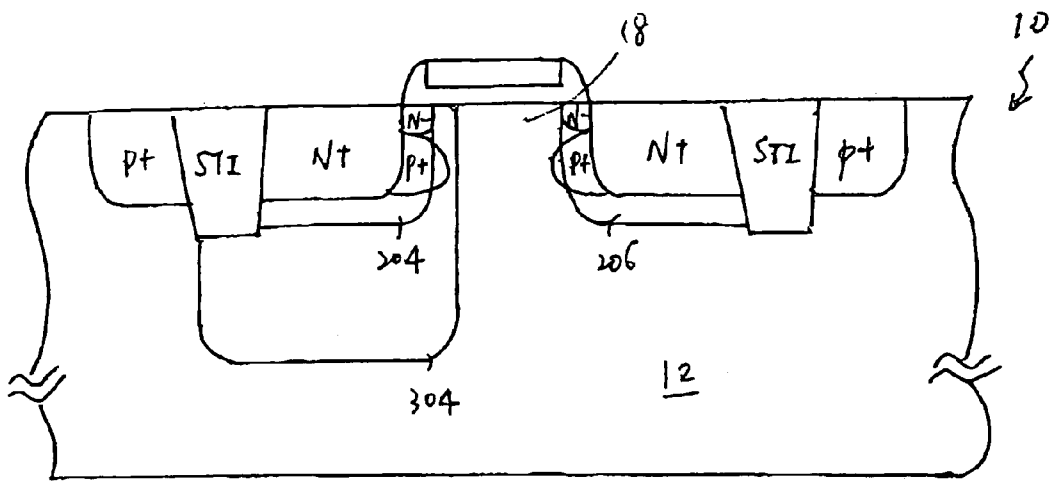


FIG. 15

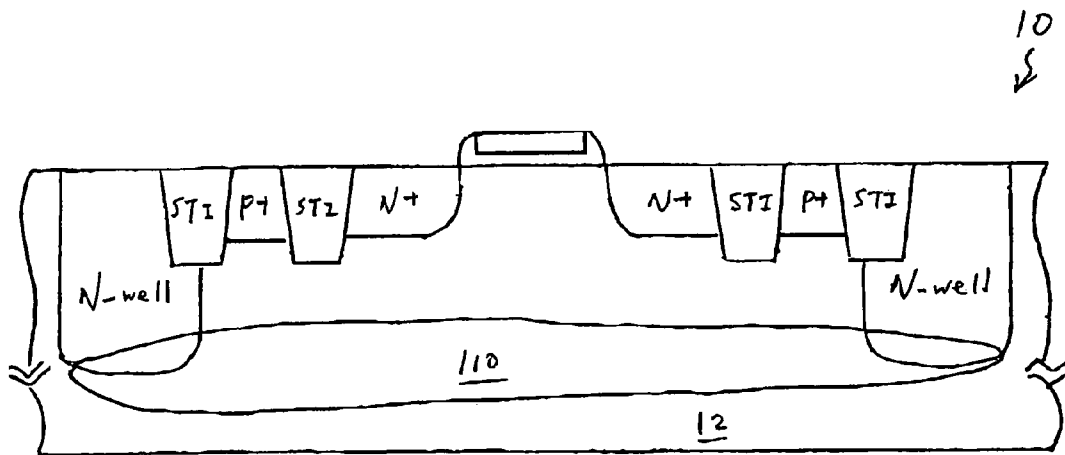


FIG. 16

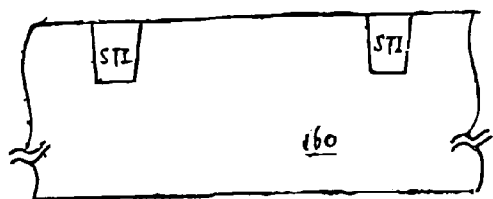


FIG. 17A

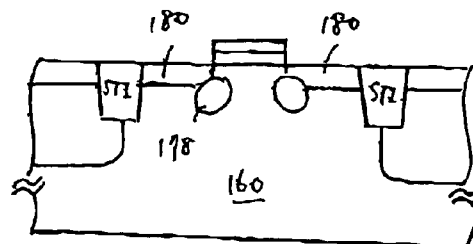


FIG. 17F

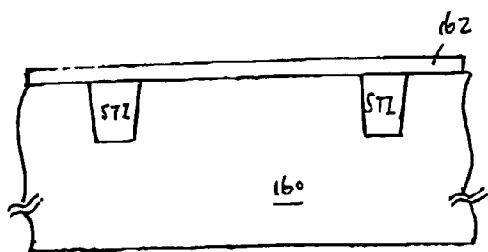


FIG. 17B

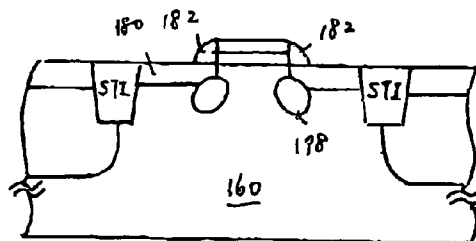


FIG. 17G

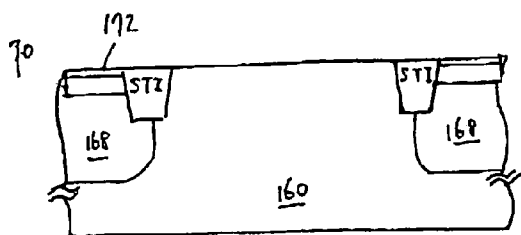


FIG. 17C

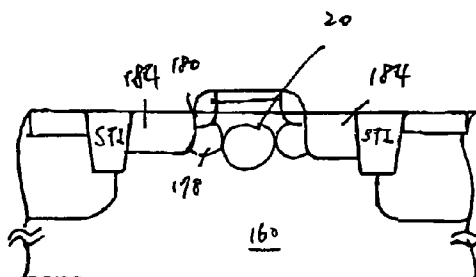


FIG. 17H

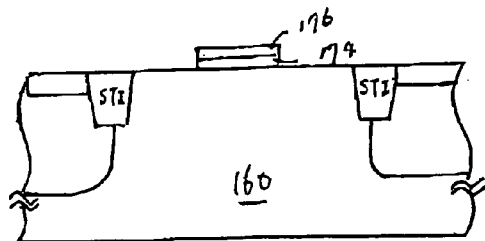


FIG. 17D

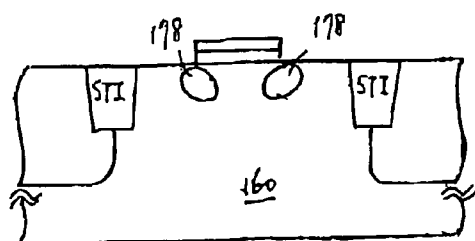


FIG. 17E

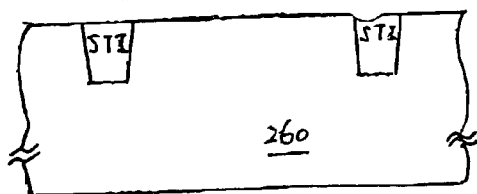


FIG. 18A

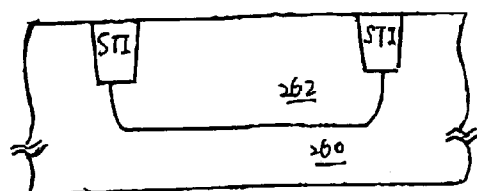


FIG. 18B

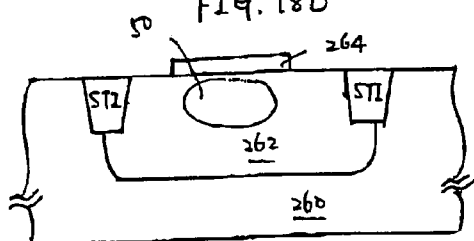


FIG. 18C

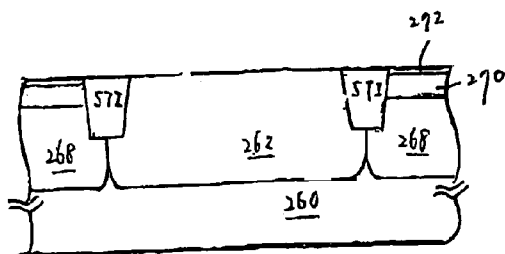


FIG. 18D

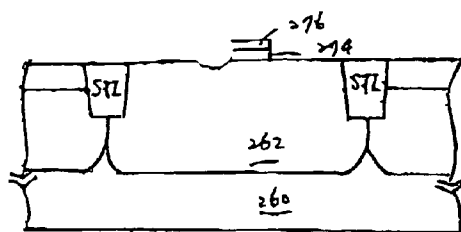


FIG. 18E

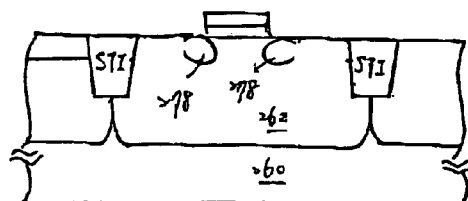


FIG. 18F

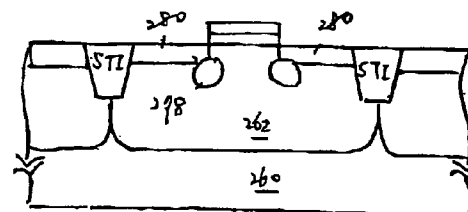


FIG. 18G

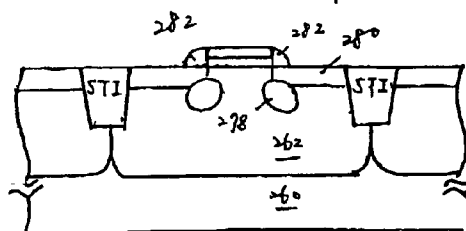


FIG. 18H

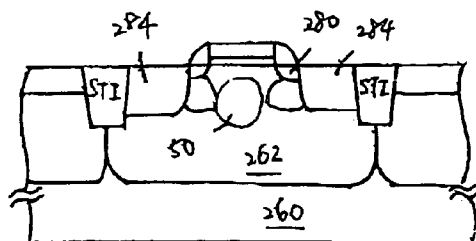


FIG. 18I

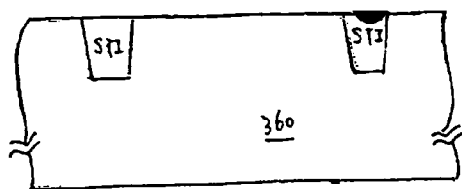


FIG. 19A

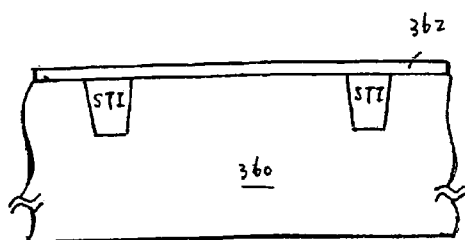


FIG. 19B

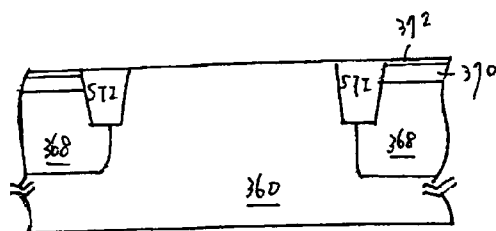


FIG. 19C

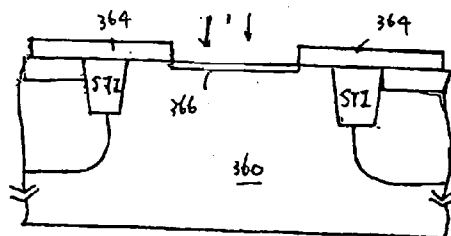


FIG. 19D

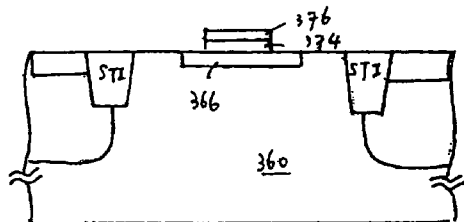


FIG. 19E

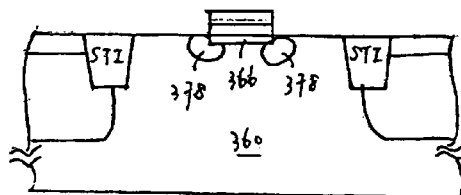


FIG. 19F

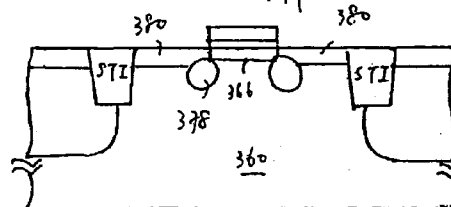


FIG. 19G

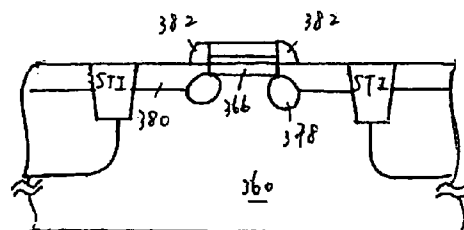


FIG. 19H

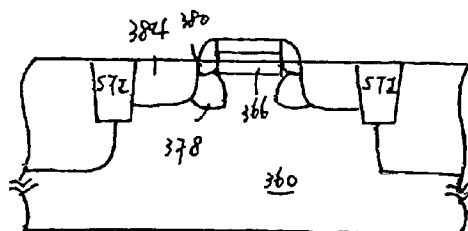


FIG. 19I

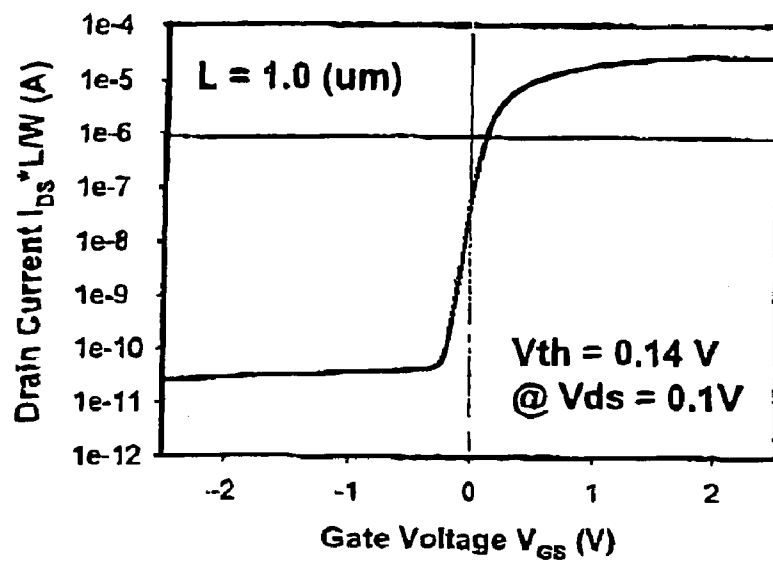


FIG. 20

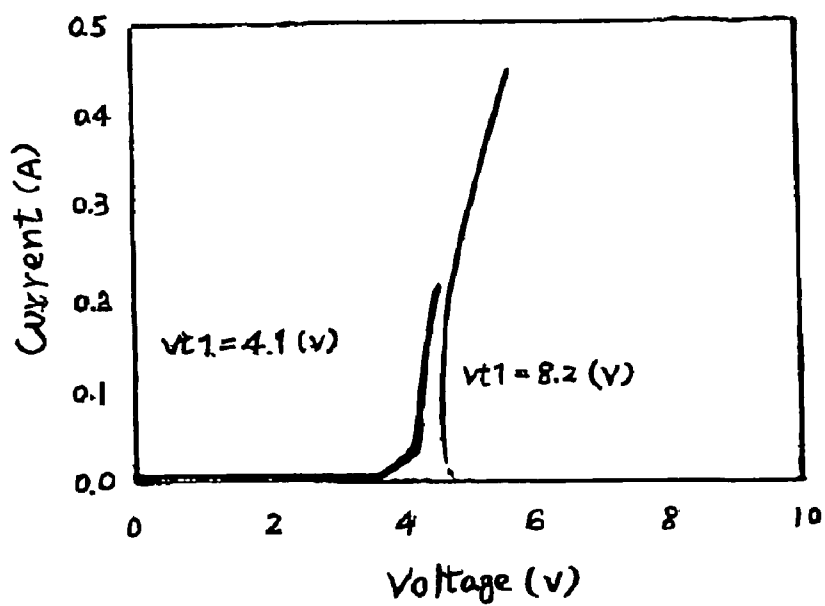


FIG. 21

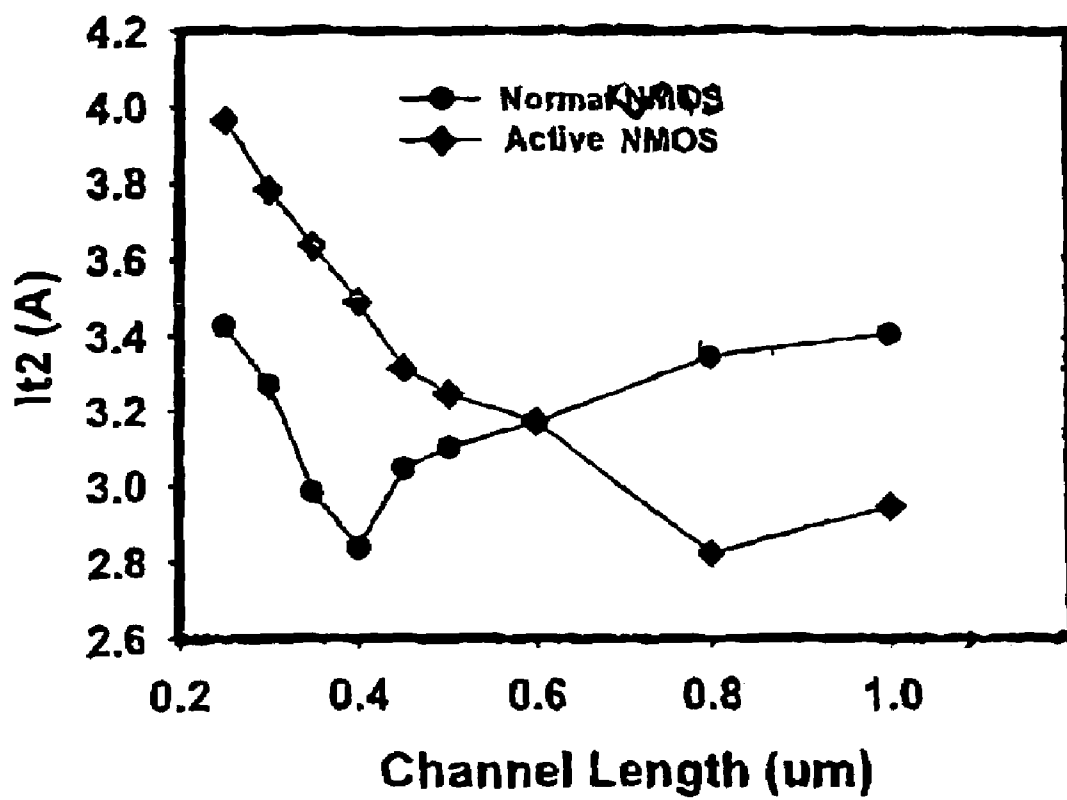


FIG. 22



1

# ELECTROSTATIC DISCHARGE PROTECTION DEVICE AND METHOD OF MANUFACTURING THE SAME

## RELATED APPLICATION

This application is a division of application Ser. No. 10/230,055, filed Aug. 29, 2002, now U.S. Pat. No. 6,882,009 which is related to U.S. patent application No. 10/230,287, entitled "ELECTROSTATIC DISCHARGE PROTECTION CIRCUIT WITH ACTIVE DEVICE," filed on Aug. 29, 2002. The entire contents of these related applications are incorporated herein by reference.

## FIELD OF THE INVENTION

This invention pertains in general to a semiconductor device, and, more particularly, to an electrostatic discharge protection device and method for manufacturing the same.

## BACKGROUND

A semiconductor integrated circuit ("IC") is generally susceptible to an electrostatic discharge ("ESD") event, which may damage or destroy the IC. An ESD event refers to a phenomenon of electrical discharge of a current (positive or negative) for a short duration during which a large amount of current is provided to the IC. The high current may be built-up from a variety of sources, such as the human body.

Advanced MOSFET transistors, such as those manufactured using sub-quarter-micron processes, have traditionally required certain processes such as silicide processes, lightly-doped drain (LDD) structures, and thin gate dielectric layers. As a result, the advanced MOSFET transistors are particularly susceptible to an ESD event.

Conventional ESD protection devices are implemented using bipolar junction transistors ("BJTs"), gate grounded NMOS ("GGNMOS") transistors, silicon controlled rectifiers ("SCR"), and silicon junction diodes, to name a few examples. Conventional NMOS devices have a threshold voltage of about 0.6V adjustable by changing the concentration of the p-type implant in the channel regions. These devices disadvantageously have slow turn-on speed and therefore poor ESD robustness.

An example of a conventional ESD protection device in input/output (I/O) pad design is shown in FIGS. 1 and 2, reproduction of FIGS. 1B and 2, respectively, of U.S. Pat. No. 6,256,184 to Gauthier, entitled "Method and Apparatus for Providing Electrostatic Discharge Protection." Gauthier describes an ESD protection structure that includes low threshold and zero threshold FETs to conduct transient ESD currents during an ESD event. Referring to FIG. 1, an NMOS **115** for ESD protection device has a low threshold voltage, and, during normal operation, is required to connect to a negative voltage source **201** at the gate to turn off channel current. Referring to FIG. 2, an ESD protection circuit **101** comprises a source diode **203** to minimize leakage current during normal IC operation.

A conventional NMOS device is generally formed in a p-well, and is manufactured by first providing a substrate and forming shallow trench isolations ("STIs") or local oxidation silicon ("LOCOS"). The steps of p-well implantation, anti-punchthrough implantation, and channel implantation then follow. In general, the p-well has the largest implant depth and the lowest doped concentration, and the channel region has the smallest implant depth and the highest doped concentration. The steps of n-well implantation, anti-punchthrough

2

implantation, and channel implantation follow then. A gate oxide layer is then formed over the substrate, and a gate is formed over the gate oxide layer. Sidewall spacers are formed contiguous with the gate. Finally, source and drain regions are formed to finish the fabrication of the NMOS in a p-well.

## SUMMARY OF THE INVENTION

In accordance with the invention, there is provided an electrostatic discharge protection device that includes a semiconductor substrate of a first dopant type, at least one source/drain pair of a second dopant type formed in the substrate, wherein the source/drain pair is separated to define a channel region therebetween, a lightly-doped region of the first dopant type defined between the source/drain pair and including at least a portion of the channel region, a gate dielectric layer formed over the substrate, and a gate formed over the gate dielectric layer and above the channel region.

In one aspect, the device includes a pocket region of the first dopant type formed adjacent one of the source/drain pair and under the gate.

In another aspect, the device includes an anti-punch-through region of the first dopant type formed under the channel region and extending between the source/drain pair.

Also in accordance with the present invention, there is provided an electrostatic discharge protection device that includes a semiconductor substrate of a first dopant type, a well region of the first dopant type formed in the substrate, a source region of a second dopant type formed in the well region, a drain region pair of a second dopant type formed in the well region and spaced apart from the source region, a channel region formed between the source and drain regions, a lightly doped region of the first dopant type defined between the source and drain regions, and a gate formed on the substrate and over the channel region.

Further in accordance with the present invention, there is provided an electrostatic discharge protection device that includes a semiconductor substrate of a first dopant type, at least one source/drain pair of a second dopant type formed in the substrate, wherein the source/drain pair is separated to define a channel region therebetween, a lightly doped region of the second dopant type defined between the source/drain pair and including at least a portion of the channel region, a gate dielectric layer formed over the substrate, and a gate formed over the gate dielectric layer and above the channel region.

In accordance with the present invention, there is provided a method of manufacturing an electrostatic discharge protection device that includes providing a semiconductor substrate of a first dopant type having a surface, masking an area of the surface of the semiconductor substrate, implanting the semiconductor substrate with a dopant of a second dopant type, implanting the semiconductor substrate with a dopant of the first dopant type, unmasking the area of the surface of the semiconductor substrate, forming at least one source/drain pair of a second dopant type in the area, wherein the source/drain pair is separated to define a channel region therebetween, and forming a gate on the substrate and over the channel region.

In one aspect, in masking an area of the surface, the method includes applying a dummy layer over the area of the surface.

In another aspect, prior to masking an area of the surface, the method includes forming a deep well region of the second dopant type in the substrate.

Also in accordance with the present invention, there is provided a method of manufacturing an electrostatic discharge protection device that includes providing a semicon-

3

ductor substrate of a first dopant type having a surface, forming a well region of the first dopant type in the semiconductor substrate, masking an area of the surface disposed on the well region of the first dopant type, implanting the semiconductor substrate with a dopant of a second dopant type, implanting the semiconductor substrate with a dopant of the first dopant type, unmasking the area of the surface disposed on the well region of the first dopant type, forming at least one source/drain pair of a second dopant type in the area, wherein the source/drain pair is separated to define a channel region therebetween; and forming a gate on the substrate and over the channel region.

Further in accordance with the present invention, there is provided a method of manufacturing an electrostatic discharge protection device that includes providing a semiconductor substrate of a first dopant type having a surface, masking a first area of the surface of the semiconductor substrate, implanting the semiconductor substrate with a dopant of a second dopant type, implanting the semiconductor substrate with a dopant of the first dopant type, unmasking the first area of the surface of the semiconductor substrate, implanting a second area in the first area with a dopant of the second dopant type, forming at least one source/drain pair of the second dopant type in the first area, wherein the source/drain pair is separated by the second area, and forming a gate on the substrate and over the second area.

Additional objects and advantages of the invention will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate several embodiments of the invention and together with the description, serve to explain the principles of the invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view of a conventional low threshold voltage ESD protection device;

FIG. 2 is a schematic diagram of a conventional low threshold voltage ESD protection circuit;

FIG. 3 is a cross-sectional view of an ESD protection device in accordance with one embodiment of the present invention;

FIG. 4 is a cross-sectional view of an ESD protection device in accordance with one embodiment of the present invention;

FIG. 5 is a cross-sectional view of an ESD protection device in accordance with another embodiment of the present invention;

FIG. 6 is a cross-sectional view of an ESD protection device in accordance with one embodiment of the present invention;

FIG. 7 is a cross-sectional view of an ESD protection device in accordance with still another embodiment of the present invention;

FIG. 8 is a cross-sectional view of an ESD protection device in accordance with one embodiment of the present invention;

4

FIG. 9 is a layout of an ESD protection device in accordance with one embodiment of the present invention;

FIG. 10 is a cross-sectional view of the ESD protection device shown in FIG. 9;

FIG. 11 is a cross-sectional view of an ESD protection device in accordance with one embodiment of the present invention;

FIG. 12 is a cross-sectional view of an ESD protection device in accordance with one embodiment of the present invention;

FIG. 13 is a cross-sectional view of an ESD protection device in accordance with one embodiment of the present invention;

FIG. 14 is a cross-sectional view of an ESD protection device in accordance with one embodiment of the present invention;

FIG. 15 is a cross-sectional view of an ESD protection device in accordance with one embodiment of the present invention;

FIG. 16 is a cross-sectional view of an ESD protection device in accordance with one embodiment of the present invention;

FIGS. 17A-17H show a method of manufacturing an ESD protection device in accordance with one embodiment of the present invention;

FIGS. 18A-18I show a method of manufacturing an ESD protection device in accordance with another embodiment of the present invention;

FIGS. 19A-19I show a method of manufacturing an ESD protection device in accordance with still another embodiment of the present invention;

FIG. 20 is a plot showing the relationship between a drain current and a gate voltage of the ESD protection device shown in FIG. 3;

FIG. 21 is a current-voltage curve of the ESD protection device shown in FIG. 3; and

FIG. 22 is a plot showing a comparison in characteristics between the ESD protection device shown in FIG. 3 and a conventional ESD protection device.

FIG. 23 is a cross-sectional view of an ESD protection device of FIG. 5 modified in accordance with another embodiment.

#### DESCRIPTION OF THE EMBODIMENTS

Reference will now be made in detail to the present embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

FIG. 3 shows a cross-sectional view of an ESD protection device 10 in accordance with one embodiment of the present invention. Referring to FIG. 3, ESD protection device 10 includes a semiconductor substrate 12 of a first dopant type, at least one source/drain pair of a second dopant type formed in the substrate 12, in which the source/drain regions 14 and 16 of each source/drain pair are spaced apart to define a channel region 18 therebetween, and a lightly doped region 20 of the first dopant type formed between the source/drain pair and including at least a portion of the channel region 18. In one embodiment, the lightly doped region 20 may include a full channel region 18. The lightly doped region 20 has a dopant concentration lower than the substrate 12. Besides, one skilled in the art would understand that which of the regions 14 and 16 is labeled the source or drain is unimportant for purposes of the present invention.

5

The ESD protection device **10** also includes a gate dielectric layer **21** disposed over the substrate **12**, and a gate **22** formed over the gate dielectric layer **21**. The gate **22** of the ESD protection device **10** includes spacers **30** of silicon oxide, polyimide or the like. In one embodiment, the ESD protection device **10** includes lightly-doped drain (LDD) regions **24** to reduce hot electron effects. In one embodiment, the ESD protection device **10** includes pocket regions **26** to reduce the influence of short transistor gate length over transistor properties such as the threshold voltage.

The ESD protection device **10** shown in FIG. 3 is an NMOS device fabricated on a substrate **12** that is lightly doped with a first type of impurities, i.e., p-type impurities. However, one skilled in the art would understand that PMOS devices are fabricated in a similar manner by substituting the p-type impurities with n-type impurities. In addition, unlike conventional NMOS devices, the ESD protection device **10** is not formed in a p-well. In fabricating the device **10**, a dummy layer (not shown) is used to mask the ESD protection device **10** from ion implants that would otherwise be necessary for conventional NMOS devices. Since the doped concentration of the channel region **18** is lower than that of the channel region of conventional NMOS devices, the threshold voltage of the ESD protection device **10** is reduced.

FIG. 4 shows a cross-sectional view of the ESD protection device **10** consistent with another embodiment of the invention. Referring to FIG. 4, the ESD protection device **10** includes an anti-punchthrough region **28** of a p-type dopant to reduce leakage current. The anti-punchthrough region **28** is formed below the lightly doped region **20**. In one embodiment, the anti-punchthrough region **28** is formed contiguous with one or all of the source and drain regions **14** and **16**, and the lightly doped region **20**.

FIG. 5 shows a cross-sectional view of an ESD protection device **40** consistent with another embodiment of the present invention. Referring to FIG. 5, the ESD protection device **40** includes a semiconductor substrate **42** of a first dopant type, a well region **60** of the first dopant type formed in the substrate **42**, at least one source/drain pair of a second dopant type formed in the well region **60**, wherein a source region **44** and a drain region **46** of a source/drain pair are spaced apart to define a channel region **48** therebetween, and a lightly doped region **50** of the first dopant type formed between the source and drain regions **44** and **46**. In one embodiment, the lightly doped region **50** includes at least a portion of the channel region **48**.

The ESD protection device **40** also includes a gate dielectric layer **53** formed over the substrate **42** and the channel region **48**, and a gate **52** formed over the gate dielectric layer **53**. The ESD protection device **40** is formed in a p-well **60**, but has not undergone any channel or anti-punchthrough implants. In fabricating the ESD protection device **40**, a dummy layer is used to mask the ESD protection device **40** from the channel and anti-punchthrough implants that would otherwise be necessary for conventional NMOS devices. As a result, the lightly doped region **50**, which may include the channel region **48**, is formed between the source and drain regions **44** and **46**. Since the doped concentration of the channel region **48** is lower than that of the conventional NMOS devices, the threshold voltage of the ESD protection device **40** is reduced. Since the p-well region **60** has a higher doped concentration than the substrate **42**, the ESD protection device **40** has a higher threshold voltage than the ESD protection device **10** shown in FIG. 3, but still has a lower threshold voltage than conventional devices.

Referring again to FIG. 5, in one embodiment, the ESD protection device **40** includes LDD regions **54** to reduce hot

6

electron effects. In another embodiment, the ESD protection device **40** includes pocket regions **56** to reduce the influence of short transistor gate length on transistor properties such as the threshold voltage. In one embodiment, the source and drain regions **44** and **46** are doped with an n-type impurity, the LDD regions **54** are doped with an n-type impurity, and the pocket regions **56** are doped with a p-type impurity.

FIG. 6 is a cross-sectional view of the ESD protection device **40** consistent with another embodiment of the invention. Referring to FIG. 6, the ESD protection device **40** includes an anti-punchthrough region **58** to reduce leakage current. In one embodiment, the anti-punchthrough region **58** is doped with a p-type impurity.

FIG. 7 is a cross-sectional view of an ESD protection device **70** consistent with still another embodiment of the present invention. Referring to FIG. 7, the ESD protection device **70** includes a semiconductor substrate **72** of a first dopant type, at least one source/drain pair of a second dopant type formed in the substrate **72**, a lightly doped channel region **78** of the second dopant type extending between a source region **74** and a drain region **76** of a source/drain pair, and a gate **82** formed on the substrate **72** and over the channel region **78**.

In fabricating the ESD protection device **70**, a dummy layer is used to mask the ESD protection device **70** from a p-well, anti-punchthrough, and channel implants that would be otherwise necessary for general NMOS devices. In contrast to the heavily doped p-type channels of conventional NMOS devices, the channel region **78** of the ESD protection device **70** is lightly doped with an n-type impurity. The lightly doped n-type channel region **78** turns the threshold voltage of the NMOS protection device **70** into a negative value so that the ESD protection device **70** is kept conductive during normal operation.

In one embodiment, the ESD protection device **70** includes pocket regions **86** to reduce the influence of short transistor gate length over transistor properties such as the threshold voltage. In one embodiment, the source and drain regions **74** and **76** are doped with an n-type impurity and the pocket regions **86** are doped with a p-type impurity.

FIG. 8 is a cross-sectional view of the ESD protection device **70** consistent with another embodiment of the invention. Referring to FIG. 8, the ESD protection device **70** includes an anti-punchthrough region **88** to reduce leakage current.

FIG. 9 shows a layout of a finger-type NMOS ESD protection device **90** in accordance with yet another embodiment of the present invention. The ESD protection device **90** includes a common gate region **92**, a common source or drain region **94** of an n-type dopant, a dielectric region **96** such as a LOCOS or trench isolation, and a p-type dopant region **98**. The finger-type device **90**, similar to the ESD protection devices **10**, **40** and **70** in FIG. 3, FIG. 5 and FIG. 7, respectively, has a lightly doped region formed under a dummy layer **100** (shown by dotted line) to reduce a threshold voltage.

FIG. 10 is a cross-sectional view of the ESD protection device **90** shown in FIG. 9 along the AA' direction. Referring to FIG. 10, the ESD protection device **90** includes at least one source/drain pair **94** and parasitic lateral bipolar junction transistor ("LBjTs") (not numbered). In operation, during an ESD event, the ESD protection device **90** achieves a drain-induced barrier lowering ("DIBL") effect, resulting in a larger substrate current  $I_{sub}$  such that the LBjTs can quickly conduct an ESD current to ground.

FIG. 11 is a cross-sectional view of the ESD protection device **10** consistent with another embodiment of the invention. Referring to FIG. 11, the ESD protection device **10**

7

includes a first diffused region **104** and a second diffused region **106**, both of n-type dopant, formed under the source region **14** and the drain region **16**, respectively. The first diffused region **104** has a larger implant depth than the source region **14**, which increases the base, or substrate, resistance  $R_{sub}$  of the ESD protection device **10**. The second diffused region **106** has a larger implant depth than the drain region **16** and functions to direct an ESD current deep into the substrate **12** to increase heat dissipation of the ESD protection device **10**. Therefore, the first diffused region **104** and the second diffused region **106** both contribute to the ESD robustness of the ESD protection device **10**. One skilled in the art would understand that the first and second diffused regions **104** and **106** may be likewise incorporated into the ESD protection device **40** of FIG. 5, device **70** of FIG. 7, and device **90** of FIG. 9.

FIG. 12 shows a cross-sectional view of the ESD protection device **10** consistent with still another embodiment of the invention. Referring to FIG. 12, the first diffused region **104** formed under the source region **14** extends into a portion of the channel region **18**. The first diffused region **104** extending into the channel region **18** prevents the parasitic LBJT (shown by dotted line) from current crowding and increase the beta value, or the gain, of the parasitic LBJT. In one embodiment, the second diffused region **106** shown in FIG. 11 formed under the drain region **16** extends into a portion of the channel region **18**. One skilled in the art would understand that the first diffused region **104** or the second diffused region **106** extending into the channel region **18** may be likewise incorporated into the ESD protection device **40** of FIG. 5, device **70** of FIG. 7, and device **90** of FIG. 9.

FIG. 13 shows a cross-sectional view of the ESD device **10** consistent with yet another embodiment of the invention. Referring to FIG. 13, the ESD protection device **10** includes a third diffused region **204** and a fourth diffused region **206**, both of which are doped with an n-type dopant, formed under the source region **14** and the drain region **16**, respectively, and extending into a portion of the LDD regions **24**. The third diffused region **204** or the fourth diffused region **206** has a smaller implant depth than the first diffused region **104** or the second diffused region **106**. Both the third and fourth diffused regions **204** and **206** function to improve the ESD robustness of the ESD protection device **10**. The third diffused region **204** or the fourth diffused region **206** may be likewise incorporated into the ESD protection device **40** of FIG. 5, device **70** of FIG. 7, and device **90** of FIG. 9. For example, adding third diffused region **204** and fourth diffused region **206** to the embodiment depicted in FIG. 5, produces an ESD protection device as depicted in FIG. 23.

FIG. 14 shows a cross-sectional view of the ESD protection device **10** consistent with yet another embodiment of the invention. Referring to FIG. 14, the ESD protection device **10** includes a fifth diffused region **304** and a sixth diffused region **306**, both doped with an n-type dopant, formed under the third and fourth diffused regions **204** and **206**, respectively. The fifth and sixth diffused regions **304** and **306** have the same functions as the first and second diffused regions **104** and **106** shown in FIG. 11, and are applicable to the ESD protection device **40** of FIG. 5, device **70** of FIG. 7, and device **90** of FIG. 9.

FIG. 15 shows a cross-sectional view of the ESD protection device **10** consistent with yet another embodiment of the invention. Referring to FIG. 15, the fifth diffused region **304** formed under the third diffused region **204** extends into a portion of the channel region **18**. The fifth diffused region **304** has the same functions as the first diffused region **104** shown in FIG. 12. In one embodiment, the sixth diffused region **306**

8

shown in FIG. 14 extends into a portion of the channel region **18**. The fifth diffused region **304** or the sixth diffused region **306** extending into the channel region **18** is applicable to the ESD protection device **40** of FIG. 5, device **70** of FIG. 7, and device **90** of FIG. 9.

FIG. 16 shows a cross-sectional view of the ESD protection device **10** consistent yet another embodiment of the invention. Referring to FIG. 16, the ESD protection device **10** includes a deep N-well region **110** to reduce leakage current. In one embodiment, the deep N-well region **110** has an implant depth of 2 to 5  $\mu\text{m}$  (micron). The deep N-well **110** is formed after the semiconductor substrate **12** is prepared. One skilled in the art would understand that the deep N-well **110** is also applicable to the ESD protection device **40** of FIG. 5, device **70** of FIG. 7, and device **90** of FIG. 9.

In addition, the present invention also provides methods for manufacturing ESD protection devices. In particular, FIGS. 17A-17H show the steps of a method in accordance with one embodiment of the present invention for manufacturing the ESD protection device **10**. Referring to FIG. 17A, the manufacturing method of the present invention begins with the formation of STIs or LOCOS in a p-type substrate **160**. In one embodiment, a deep N-well (not shown) is formed prior to the formation of the STIs and LOCOS. Referring to FIG. 17B, a photoresist layer **162** is provided over the substrate **160**, and then patterned and defined. The patterned and defined photoresist layer **162** serves as a dummy, or sacrificial, layer to mask the portion of the substrate **160** covered by the photoresist **162** from subsequent implantation steps.

The steps of well implantation, anti-punchthrough implantation, and channel implantation are then performed. Referring to FIG. 17C, in areas not masked by the dummy layer, an n-well **168**, an anti-punchthrough region **170**, and a channel **172** are formed. The lightly doped p-type region **20** shown in FIG. 3 will be later defined to achieve the desired property of low threshold voltage. The photoresist **162** is then removed.

Conventional NMOS manufacturing steps may now follow. Referring to FIG. 17D, a gate oxide layer **174** is formed over the substrate **160** and a gate conductive layer **176**, such as polysilicon, is deposited over the gate oxide layer **174**. The gate oxide layer **174** and gate conductive layer **176** are patterned and etched.

Referring to FIG. 17E, p-type pocket regions **178** may be optionally formed using an angled implant process. Referring to FIG. 17F, n-type LDD regions **180** are optionally formed. Referring to FIG. 17G, sidewall spacers **182** are formed contiguous with the patterned and etched gate oxide layer **174** and gate conductive layer **176**. Referring to FIG. 17H, source and drain regions **184** are formed and the lightly doped p-type region **20** is defined between the source/drain pair **184**. The manufacturing method of the present invention is therefore fully compatible with conventional CMOS processes.

Although not particularly described, the method of the present invention may optionally include forming the anti-punchthrough region **28** shown in FIG. 4, the first or second diffused region **104** or **106** shown in FIG. 11, the third or fourth diffused region **204** or **206** shown in FIG. 13, or the fifth or sixth diffused region **304** or **306** shown in FIG. 14 by conventional CMOS processes.

FIGS. 18A-18I show the steps of a method for manufacturing the ESD protection device **40**. Referring to FIG. 18A, the manufacturing method of the invention begins by providing a p-type substrate **260** and forming STIs or LOCOS in the substrate **260**. In one embodiment, after providing the substrate **260**, a deep N-well (not shown) is formed in the substrate **260**. Referring to FIG. 18B, a p-well region **262** is formed in the substrate **260** using conventional process.

Referring to FIG. 18C, a photoresist layer 264 which serves as a dummy layer is deposited over the substrate 260. The photoresist layer 264 is then patterned and defined, and functions to mask the portion of the substrate 260 covered by the photoresist 264 from the subsequent implantation steps. Following the steps of anti-punchthrough implantation, and the channel implantation, the remaining steps shown in FIGS. 18D to 18I are similar to those of FIGS. 17C to 17H. The lightly doped p-type region 50 will be later defined to achieve the desired property of low threshold voltage.

As shown in FIG. 18D, an n-well 268, anti-punchthrough region 270, and a channel 272 are formed in the substrate 260 through n-well implantation, anti-punchthrough implantation, and channel implantation steps. The patterned and defined photoresist layer 264 is removed. Referring to 18E, a gate oxide layer 274 is formed over the substrate 260 and a gate conductive layer 276 is formed over the gate oxide layer 274. The layers 274 and 276 are later patterned and etched.

As shown in FIG. 18F, p-type pocket regions 278 may be optionally formed using angled implantation steps. Referring to FIG. 18G, n-type LDD regions 280 may also be optionally formed. In FIG. 18H, sidewall spacers 282 are formed contiguous with the etched gate oxide layer 274 and gate conductive layer 276. The source and drain regions 284 are then formed and the lightly-doped p-type region 50 is defined between the source/drain pair 284 as shown in FIG. 18I.

FIGS. 19A-19I show the steps of a method in accordance with one embodiment of the present invention for manufacturing the ESD protection device 70. Referring to FIG. 19A, the method of the invention begins with providing a p-type substrate 360 and forming STIs or a LOCOS in the substrate 360. In one embodiment, a deep N-well (not shown) is formed prior to the formation of the STIs or LOCOS. Referring to FIG. 19B, a first photoresist layer 362 is provided over the substrate 360, and then patterned and defined. The patterned and defined first photoresist layer 362 serves as a dummy layer to mask the portion of the substrate 360 covered by the photoresist 362 from subsequent implantation steps.

The steps of n-well implantation, anti-punchthrough implantation, and channel implantation are then performed. Referring to FIG. 19C, an n-well 368, an anti-punchthrough region 370, and a channel 372 are formed. The first photoresist layer 362 is then removed.

Referring to FIG. 19D, a second photoresist 364 is provided over the substrate 360, and is then patterned and defined. With the second photoresist 364 acting as a mask, an n-type impurity is implanted into the substrate 360 to form a lightly-doped n-type region 366. The lightly-doped n-type region 366, like the lightly-doped p-type region 20 of FIG. 3 or region 50 of FIG. 5, contributes to the desired property of low threshold voltage. Subsequent to the step of FIG. 19D, the remaining steps shown in FIGS. 19E to 19I are the same as the steps shown and described in FIGS. 17D to 17H.

FIG. 20 is a plot showing the relationship between the drain current  $I_{ds}$  and the gate voltage  $V_{gs}$  of the ESD protection device 10 shown in FIG. 3. Referring to FIG. 20, when the gate voltage is at 0.14V, the drain current is at 1 uA. Accordingly, the threshold voltage of the device 10 of the present invention, 0.14V, is much lower than 0.6V, the threshold voltage of conventional MOSFETs.

FIG. 21 is current-voltage curve of the ESD protection device 10 shown in FIG. 3. As shown in FIG. 21, the breakdown voltage ( $V_{t1}$ ) of the conventional MOSFETs is about 8.2V, while the breakdown voltage of the device 10 of the present invention is 4.2V. As a result, the ESD protection device 10 of the present invention turns on faster than conventional MOSFETs. The lower  $V_{t1}$  value of the ESD pro-

tection device 10 is due to the DIBL effect, which results from a large substrate current to enable quicker conduction by the parasitic BJTs. In normal operations, a negative voltage source of about -0.4V may be applied to the gate of the ESD protection device 10 so as to prevent leakage current.

FIG. 22 is a plot comparing the threshold current values of the ESD protection device 10 show in FIG. 3 and a conventional device. As shown in FIG. 22, when the channel length is less than 0.6 $\mu$ m, the ESD protection device 10 is more robust for ESD protection than conventional MOSFETs by an average of approximately 20%.

Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the invention being indicated by the following claims.

What is claimed is:

1. A method, comprising:

providing a semiconductor substrate of a first dopant type; forming a well region of the first dopant type in the substrate;

forming a lightly doped region of the first dopant type in the well region;

forming at least one source/drain pair of a second dopant type in the substrate, wherein a source region of the source/drain pair is separated from a drain region of the source/drain pair by a channel region;

forming a gate on the substrate and over both the channel region and the lightly doped region so that the lightly doped region is directly below a central portion of the gate;

forming lightly doped drain (LDD) regions of the second dopant type adjacent to the gate;

forming a first diffused region of the second dopant type under the drain region of the source/drain pair; and forming a second diffused region of the second dopant type under the source region of the source/drain pair.

2. The method of claim 1, wherein the gate is formed over the well region of the first dopant type.

3. The method of claim 1, further comprising forming a sidewall spacer adjacent to the gate and over the LDD regions.

4. The method of claim 1, wherein the first dopant type comprises a p-type dopant, and wherein the second dopant type comprises an n-type dopant.

5. The method of claim 1, wherein the lightly doped region is formed to be contiguous with both the source region and the drain region.

6. The method of claim 1, wherein the first and second diffused regions extend into a portion of the LDD regions.

7. The method of claim 6, further comprising forming pocket regions of the first dopant type adjacent to the source and drain regions and below the LDD regions.

8. The method of claim 7, wherein the lightly doped region is formed to be contiguous with the source region and the drain region through the pocket regions.

9. A method, comprising:

providing a semiconductor substrate of a first dopant type; forming at least one source/drain pair of a second dopant type in the substrate, wherein a source region of the source/drain pair is separated from a drain region of the source/drain pair by a channel region;

forming a gate on the substrate and over the channel region; forming lightly doped drain (LDD) regions of the second dopant type adjacent to the gate;

forming a first diffused region of the second dopant type under the drain region of the source/drain pair;

**11**

forming a second diffused region of the second dopant type under the source region of the source/drain pair; and forming a third diffused region of the second dopant type under the first diffused region.

10. The method of claim 9, further comprising forming a sidewall spacer adjacent to the gate and over the LDD regions. 5

11. The method of claim 9, wherein the first dopant type comprises a p-type dopant, and wherein the second dopant type comprises an n-type dopant.

12. The method of claim 9, wherein the first and second diffused regions extend into a portion of the LDD regions. 10

13. The method of claim 9, further comprising forming pocket regions of the first dopant type adjacent to the source and drain regions and below the LDD regions.

14. The method of claim 13, wherein the first and second diffused regions extend into a portion of the LDD regions and the pocket regions. 15

15. The method of claim 9, further comprising:

forming isolation regions adjacent to the source and drain regions; and

forming doped regions of the first dopant type adjacent to the source and drain regions. 20

16. The method of claim 9, further comprising:

forming a third diffused region of the second dopant type under the first diffused regions; and

forming a fourth diffused region of the second dopant type under the second diffused region. 25

17. A method, comprising:

providing a semiconductor substrate of a first dopant type; forming at least one source/drain pair of a second dopant 30

type in the substrate, wherein a source region of the source/drain pair is separated from a drain region of the source/drain pair by a channel region;

**12**

forming a gate on the substrate and over the channel region; forming pocket regions of the first dopant type adjacent to the source and drain regions in the channel region;

forming a first diffused region of the second dopant type under the drain region of the source/drain pair;

forming a second diffused region of the second dopant type under the source region of the source/drain pair; and

forming a third diffused region of the second dopant type under the first diffused region;

wherein a region under the second diffused region is a portion of the substrate having the first dopant type.

18. The method of claim 17, further comprising forming lightly doped drain (LDD) regions of the second dopant type adjacent to the gate.

19. The method of claim 18, further comprising forming a sidewall spacer adjacent to the gate and over the LDD regions.

20. The method of claim 18, wherein the first and second diffused regions extend into a portion of the LDD regions.

21. The method of claim 18, wherein the pocket regions are below the LDD regions. 20

22. The method of claim 21, wherein the first and second diffused regions extend into a portion of the LDD regions and the pocket regions.

23. The method of claim 17, wherein the first dopant type comprises a p-type dopant, and wherein the second dopant type comprises an n-type dopant. 25

24. The method of claim 17, further comprising:

forming isolation regions adjacent to the source and drain regions; and

forming doped regions of the first dopant type adjacent to the source and drain regions.

\* \* \* \* \*