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- (54) **ELECTROSTATIC DISCHARGE PROTECTION CIRCUIT**
- (71) Applicant: **Novatek Microelectronics Corp.**,
Hsinchu (TW)
- (72) Inventors: **Federico Agustin Altolaguirre**,
Hsinchu County (TW); **Ming-Dou Ker**,
Hsinchu County (TW); **Tzu-Chien Tzeng**,
Hsinchu (TW); **Ju-Lin Huang**,
Hsinchu County (TW)
- (73) Assignee: **Novatek Microelectronics Corp.**,
Hsinchu (TW)
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H02H 9/04 (2006.01)
H01L 27/06 (2006.01)

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(58) **Field of Classification Search**
CPC H01L 27/0262; H01L 27/0292; H01L 27/0635; H02H 9/046
See application file for complete search history.

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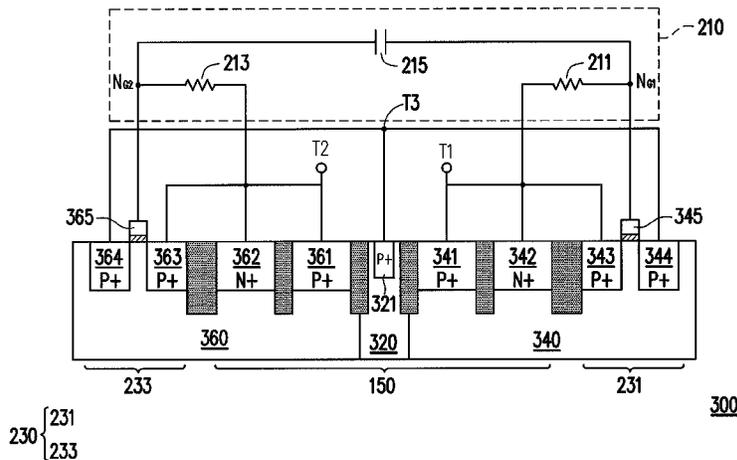
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Primary Examiner — Zeev V Kitov
(74) *Attorney, Agent, or Firm* — JCIPRNET

(57) **ABSTRACT**

In the disclosure, an electrostatic discharge (ESD) protection circuit is coupled between a first power rail and a second power rail to discharge any ESD stress. The ESD protection circuit includes a detection circuit, a triggering circuit, and a dual silicon controlled rectifier (DSCR) device. When an ESD stresses is being applied to the first or second power rail, the detection circuit may first detect the ESD stresses and output a detection signal to the triggering circuit. The triggering circuit generates a triggering signal based on the detection signal and the polarity of the ESD stress. Then, the DSCR device is symmetrically triggered based on the triggering signal received at a common node between at least two transistors of the same type. The exemplary ESD protection circuit may be implemented in nanoscale manufactured integrated circuit and achieve good ESD robustness while maintaining low standby leakage current and relatively small silicon footprint.

14 Claims, 8 Drawing Sheets



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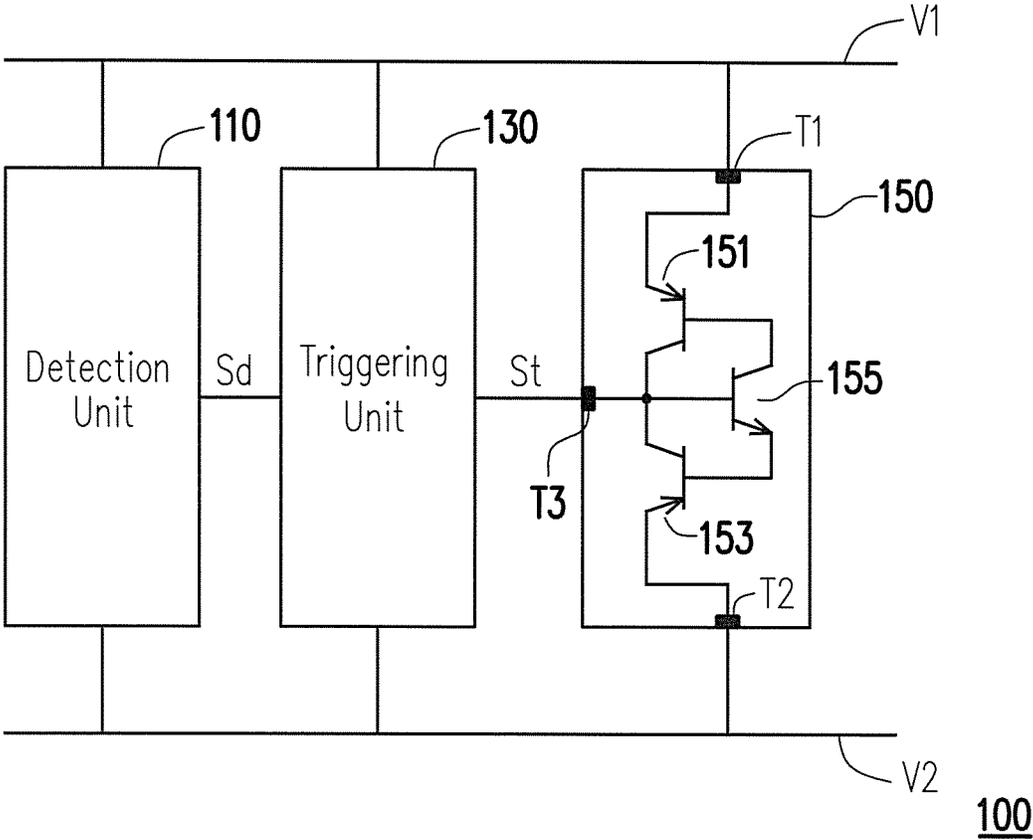
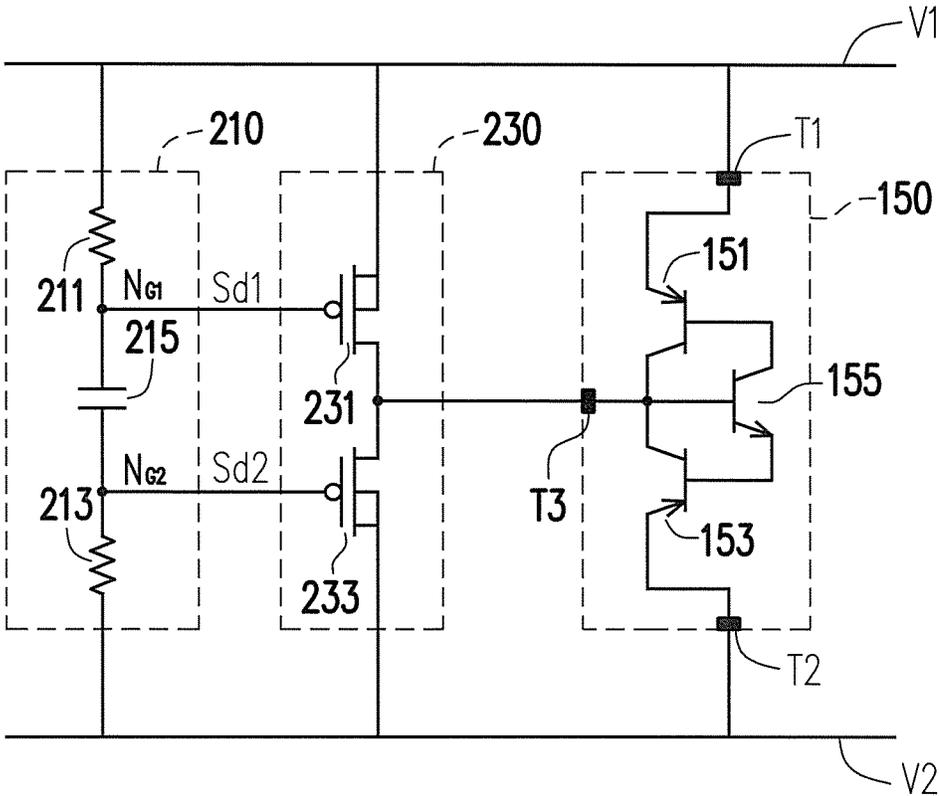


FIG. 1



200

FIG. 2A

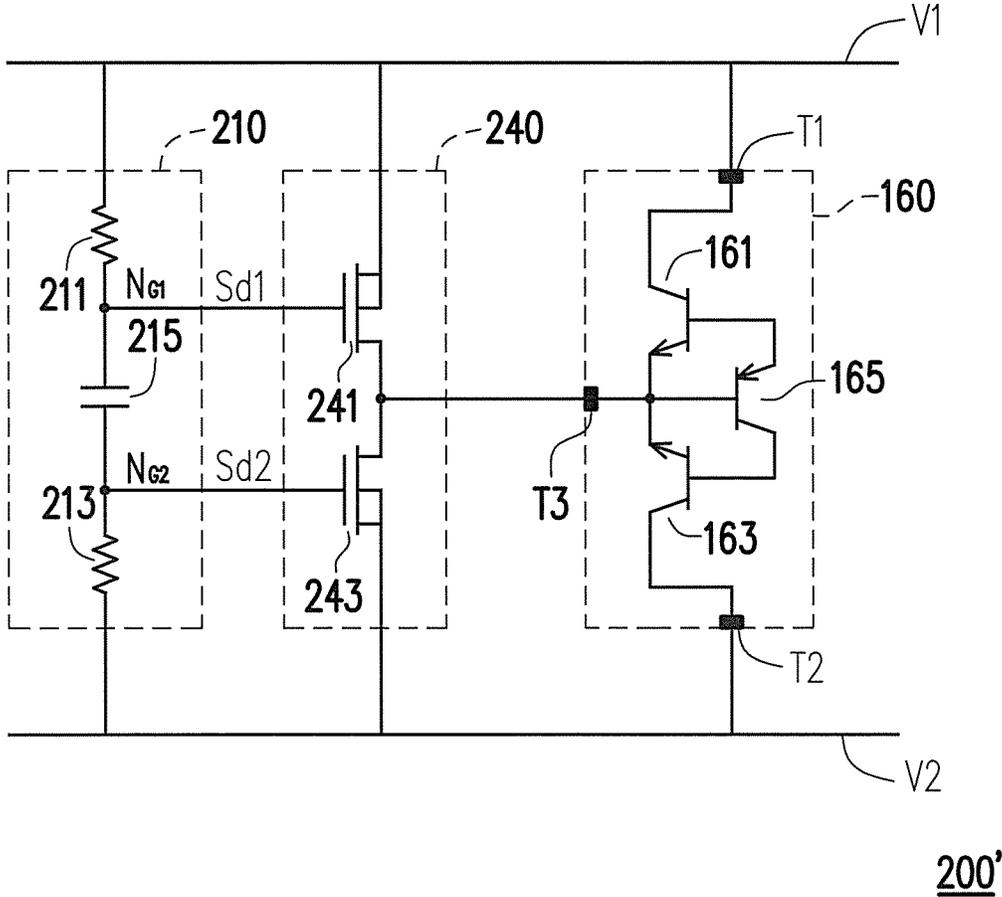


FIG. 2B

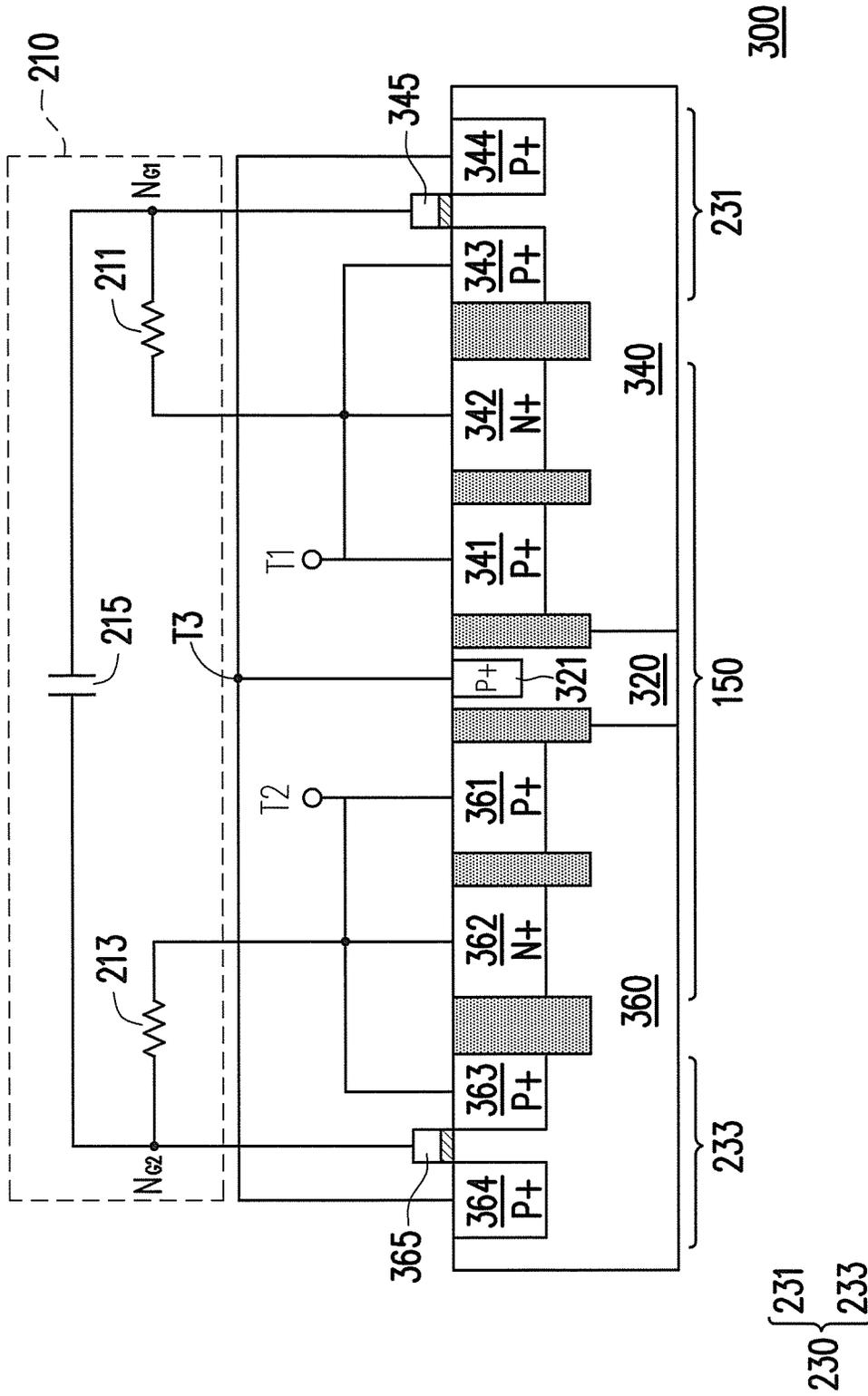


FIG. 3

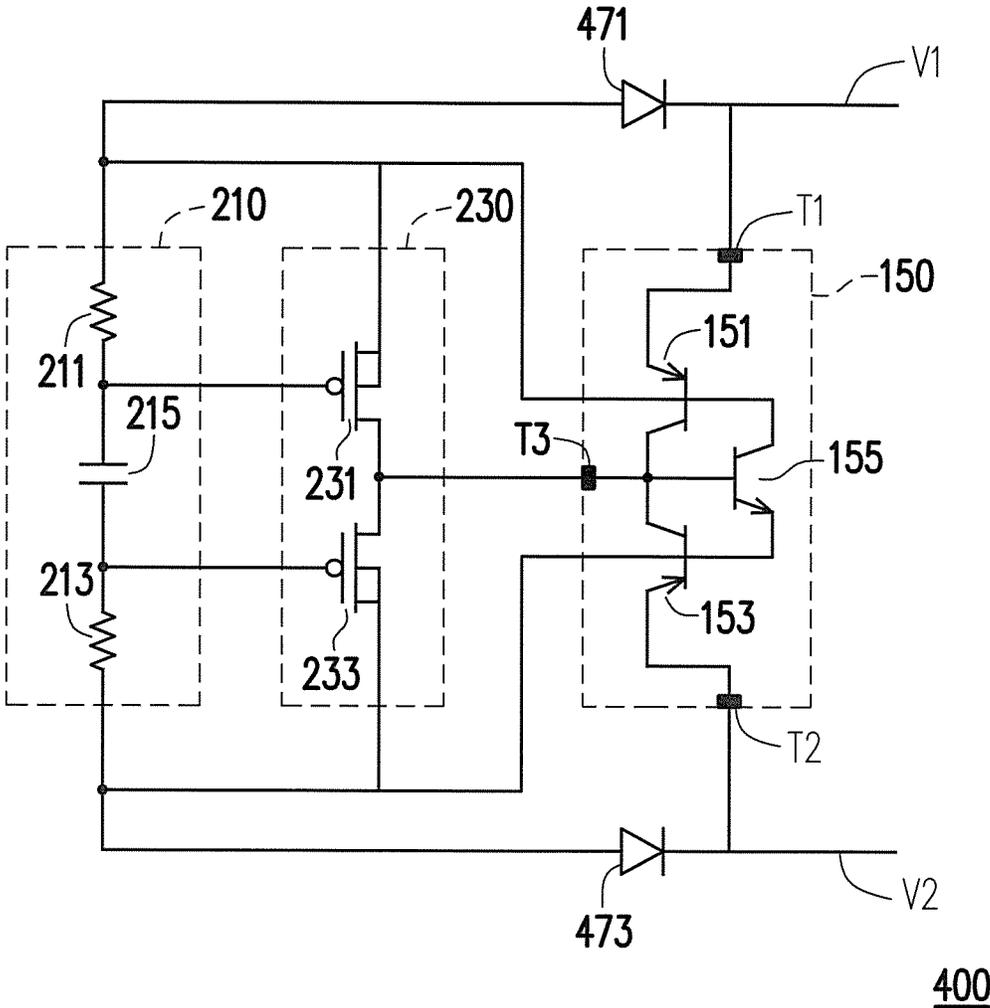


FIG. 4

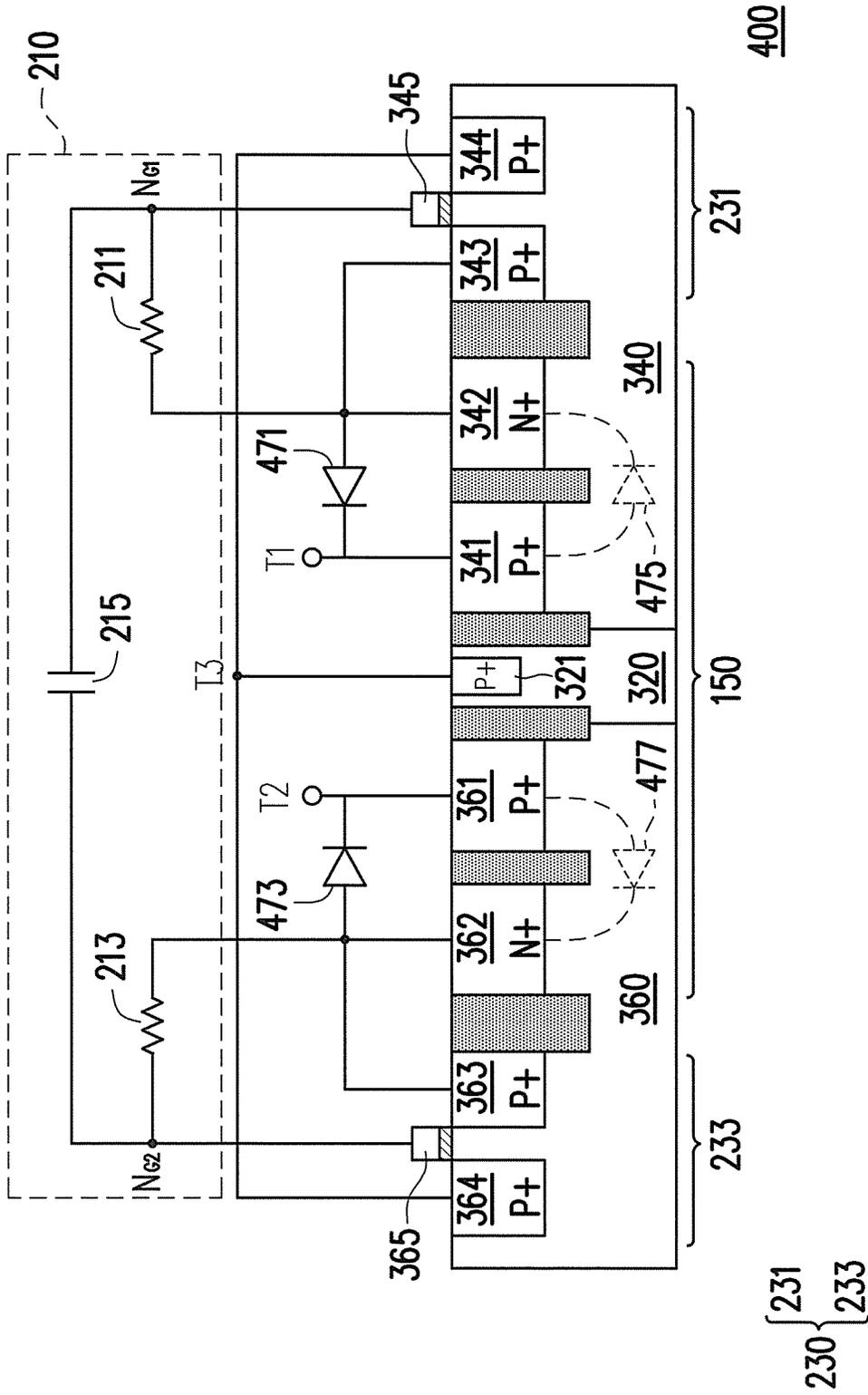


FIG. 5

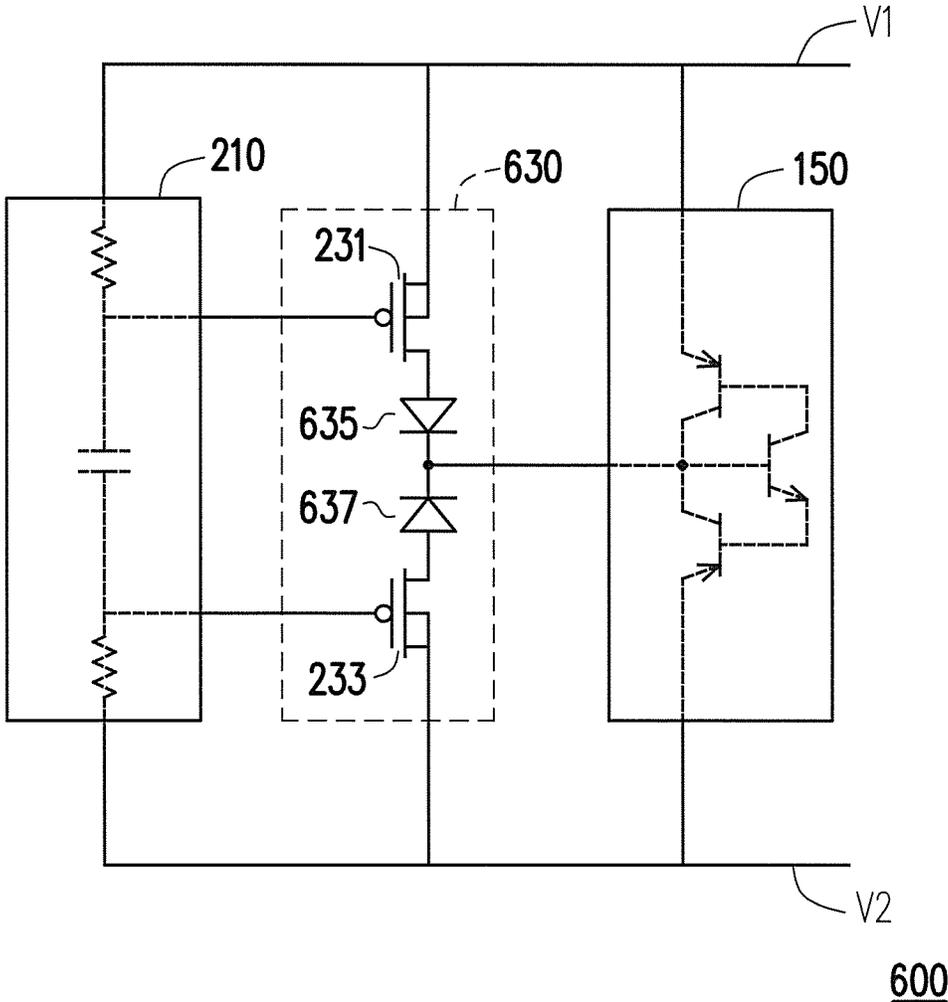


FIG. 6

600

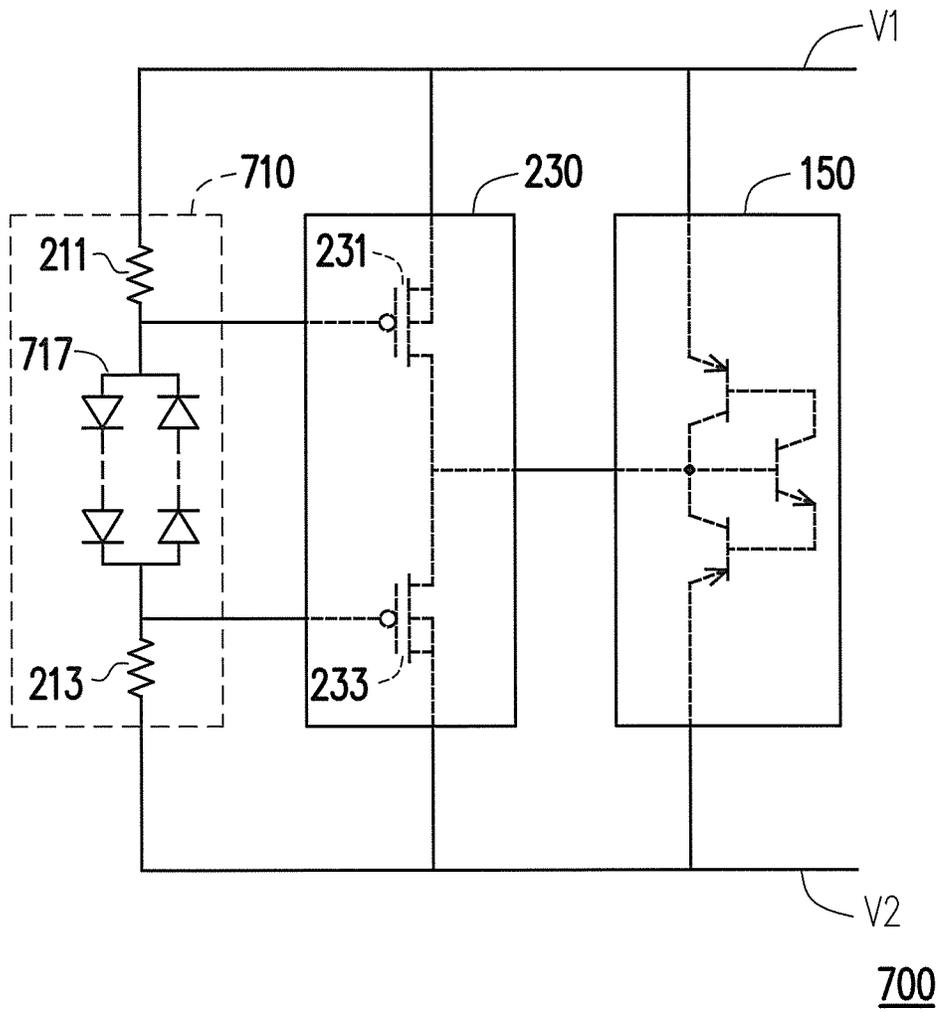


FIG. 7

ELECTROSTATIC DISCHARGE PROTECTION CIRCUIT

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the priority benefits of U.S. provisional application Ser. No. 62/213,641, filed on Sep. 3, 2015. The entirety of the above-mentioned patent application is hereby incorporated by reference herein and made a part of this specification.

BACKGROUND OF THE INVENTION

Field of Invention

The invention relates to electrostatic discharge (ESD) protection. Particularly, the invention relates to an ESD protection circuit discharging ESD stress from power rails.

Description of Related Art

In the field of integrated circuit (IC), electrostatic discharge (ESD) protection is an important task on the reliability of the ICs, where a proper ESD protection is needed to discharge any ESD stresses to protect internal circuits from being damaged. Generally, the ESD stresses may occur between pins (pin-to-pin ESD stress), one power rail to another power rail (e.g., VDD-to-VSS ESD stress, VSS-to-VDD ESD stress or domain-to-domain ESD stress).

In the advanced IC technology, ICs are designed to have at least two power domains, for example, one for analog circuits and another for digital circuits, different voltage levels for different digital circuits, etc. In the multiple power domain scheme, extra ESD protection elements are required across the power domains (domain-to-domain protection), as every pin-to-pin ESD combination must be protected.

Conventionally, a silicon controlled rectifier (SCR) or a metal-oxide semiconductor (MOS) transistor is used as ESD clamps to direct and conduct the ESD current properly. However, as both the SCR and the MOS transistor can only operate with a fixed polarity due to the parasitic diodes in their structure, thus they cannot be used for the domain-to-domain ESD protection.

Another commonly used ESD protection element is an antiparallel diode string. The number of diodes on each string may be selected according the voltages on each node in order to avoid conduction under normal circuit operation. However, the antiparallel diodes require large silicon footprint area, especially if the required voltage drop is too large. The diode string is also known to suffer from large leakage current in the nanoscale IC manufacturing processes.

To meet the requirement of conducting the ESD stresses in both directions, another symmetrical device, a dual-SCR (DSCR) device is utilized, which requires smaller silicon footprint than the antiparallel diodes for the same ESD protection level. However, the DSCR device requires the addition of a fully symmetrical triggering circuit. For example, in a ground-to-ground ESD clamp **100** shown in FIG. 1 of the U.S. Pat. No. 7,825,429, trigger elements **114** and **116** integrated by diode strings **110** (1-N) and **112** (1-N) have been utilized to set the trigger voltage of each side of the DSCR device, made of transistors **102**, **104**, **106** and resistors **108** and **110**, at which each diode strings will conduct current and trigger the DSCR device. However, diode strings are known to have a relatively large leakage current in the nanoscale IC manufacturing processes and requires large footprint.

SUMMARY OF THE INVENTION

In the disclosure, an electrostatic discharge (ESD) protection circuit is provided. The ESD protection circuit

includes a detection circuit, a triggering circuit and a dual-directional silicon controlled rectifier (DSCR) device. The detection circuit is coupled between a first power rail and a second power rail for detecting an ESD stress from the first power rail or the second power rail and outputting a detection signal according to the ESD stress. The triggering circuit is coupled to the detection circuit for receiving the detection signal and outputting a triggering signal according to the detection signal. In addition, the DSCR device includes a first terminal coupled to the first power rail, a second terminal coupled to the second power rail, a third terminal coupled to the triggering circuit to receive the triggering signal, and at least two transistors of a first type (a first transistor and a second transistor). The DSCR device is configured to discharge the ESD stress according to the triggering signal, wherein the third terminal is coupled to a common node between at least two transistors of the first type. The DSCR device further includes a third transistor of a second type, having a base terminal coupled to the common node, a first terminal coupled to the base terminal of the second transistor of the first type, and a second terminal coupled to the base of the first transistor of the first type.

According to one of the embodiment, the first transistor is formed by a first region of a second doping type disposed in a first well of a first doping type, the first well of the first doping type, and a third well of the second doping type. The second transistor is formed by a second region of the second doping type disposed in a second well of the first doping type, the second well of the first doping type, and the third well of the second doping type. In addition, the third transistor is formed by the first well of the first doping type, the third well of the second doping type disposed between the first well of the first doping type and the second well of the first doping type, wherein the common node of the first transistor, the second transistor and the third transistor is formed by the third well.

According to one of the embodiments of the disclosure, the ESD protection circuit of further includes a fourth diode coupled between the first power rail and the detection circuit, and a fifth diode coupled between the second power rail and the detection circuit.

According to one of the embodiments of the disclosure, the triggering circuit includes a fourth transistor and a fifth transistor. The fourth transistor includes a first terminal coupled to the first power rail, a second terminal coupled to the third terminal of the DSCR device, and a control terminal coupled to the detection circuit. The fifth transistor includes a first terminal coupled to the second power rail, a second terminal coupled to the second terminal of the fourth transistor, and a control terminal coupled to the detection circuit.

According to one of the embodiments of the disclosure, the triggering circuit further includes a first diode and a second diode coupled between the fourth and fifth transistors.

According to one of the embodiments of the disclosure, the detection circuit includes a first resistor, a second resistor, and a first capacitor. The first resistor is coupled between the first power rail and the control terminal of the fourth transistor of the triggering circuit. The second resistor is coupled between the second power rail and the control terminal of the fifth transistor of the triggering circuit. In addition, the first capacitor is coupled between the first resistor and the second resistor.

According to one of the embodiments of the disclosure, the detection circuit includes a first resistor, a second resistor, and an anti-parallel diode string. The first resistor, coupled between the first power rail and the control terminal of the fourth transistor of the triggering circuit. The second resistor, coupled between the second power rail and the control terminal of the fifth transistor of the triggering circuit. The anti-parallel diode string, coupled between the first resistor and the second resistor.

The disclosure provides an ESD protection circuit coupled between a first power rail or a second power rail, which effectively discharges any ESD stress occurred on the first or second power rail. The ESD protection circuit utilizes a dual silicon controlled rectifier (DSCR) device with a triggering circuit that symmetrically triggers the DSCR device in response to polarities of the ESD stress. The exemplary ESD protection circuit may be implemented in nanoscale manufactured integrated circuit and achieve good ESD robustness while maintaining low standby leakage current and relatively small silicon footprint.

In order to make the aforementioned and other features and advantages of the disclosure more comprehensible, embodiments accompanying figures are described in detail below.

It should be understood, however, that this summary may not contain all of the aspect and embodiments of the present disclosure and is therefore not meant to be limiting or restrictive in any manner. Also the present disclosure would include improvements and modifications which are obvious to one skilled in the art.

BRIEF DESCRIPTION OF THE DRAWINGS

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

FIG. 1 is a diagram illustrating an electrostatic discharge (ESD) protection circuit according to one of the embodiments of the disclosure.

FIG. 2A is an equivalent circuit diagram illustrating an ESD protection circuit according to one of the embodiments of the disclosure.

FIG. 2B is an equivalent circuit diagram illustrating an ESD protection circuit according to one of the embodiments of the disclosure.

FIG. 3 is a cross-sectional diagram illustrating a structure layout of an ESD protection circuit according to one of the embodiments of the disclosure.

FIG. 4 is an equivalent circuit diagram illustrating an ESD protection circuit according to one of the embodiments of the disclosure.

FIG. 5 is a cross sectional diagram illustrating an ESD protection circuit according to one of the embodiments of the disclosure.

FIG. 6 is a circuit diagram illustrating an ESD protection circuit according to one of the embodiments of the disclosure.

FIG. 7 is a circuit diagram illustrating an ESD protection circuit according to one of the embodiments of the disclosure.

DESCRIPTION OF EMBODIMENTS

Reference will now be made in detail to the present embodiments of the disclosure, examples of which are

illustrated in the accompanying drawings. Wherever possible, the same reference numbers are used in the drawings and the description to refer to the same or like parts.

No element, act, or instruction used in the detailed description of disclosed embodiments of the present application should be construed as absolutely critical or essential to the present disclosure unless explicitly described as such. Also, as used herein, the singular forms “a,” “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. Furthermore, when an element is referred to as being “connected” or “coupled” to another element, it may be directly connected or coupled to the other element or intervening elements may be presented.

Embodiments of the disclosure provide an electrostatic discharge (ESD) protection circuit utilizing a dual silicon controlled rectifier (DSCR) device that is symmetrically triggered by a triggering circuit. The exemplary ESD protection circuit may be implemented in nanoscale manufactured integrated circuit and achieve good ESD robustness while maintaining low standby leakage current and relatively small silicon footprint.

FIG. 1 is a diagram illustrating an ESD protection circuit **100** according to one of the embodiments of the disclosure. With reference to FIG. 1, the ESD protection circuit **100** is coupled between a first power rail V_1 and a second power rail V_2 providing a path to discharge any ESD stresses. In the embodiment, the ESD protection circuit **100** includes a detection circuit **110**, a triggering circuit **130**, and a DSCR device **150**.

The detection circuit **110** is coupled between the first power rail V_1 and the second power rail V_2 as to detect an ESD stress from either the first power rail V_1 or the second power rail V_2 , where polarity of the ESD stress may be negative or positive. Then, the detection circuit **110** outputs a detection signal S_d according to the detected ESD stress.

The triggering circuit **130** is coupled to the detection circuit **110** to receive the detection signal S_d generated based on the ESD stress being applied to the first or second power rails V_1 , V_2 . Upon the detection of the ESD stress, i.e., based on the detection signal S_d , the triggering circuit **130** outputs a triggering signal S_t (e.g., a triggering current) to control the DSCR device **150**. The DSCR device **150** is then enabled to discharge the ESD stress being applied to the first and/or second power rails V_1 , V_2 .

The DSCR device **150** has a first terminal T_1 coupled to the first power rail V_1 , a second terminal T_2 coupled to the second power rail V_2 , and a third terminal T_3 coupled to the triggering circuit **130**. In detail, the DSCR device **150** includes at least two transistors of the same type connected in series between the first and second power rails V_1 , V_2 , and the third terminal T_3 is coupled to a node commonly jointed by the transistors of the same type (also referred to as a triggering node). One end of the transistors of the same type is coupled to the first power rail V_1 , and another end of the transistors of the same type is coupled to the second power rail V_2 .

In the present embodiment, the DSCR device **150** includes the at least two transistors of the same type described above, e.g., a first transistor **151**, a second transistor **153**, and a third transistor **155** that has a type different from the first and second transistors **151**, **153**. In the example of FIG. 1, the DSCR device **150** is a N-well based DSCR (nDSCR) device, and the first transistor **151**, the second transistor **153**, and the third transistor **155** may be bipolar junction transistors (BJT), where the first and second transistors **151**, **153** may be PNP BJT and the third transistor **155** may be NPN BJT.

The structure of the DSCR device **150** would be described in detail below. The first transistor **151** of the DSCR device **150** has a base terminal, a first terminal and a second terminal. The first terminal (emitter) of the first transistor **151** is coupled to the first power rail **V1** through the first terminal **T1** of the DSCR device **150**. The second transistor **153** of the DSCR device **150** has a base terminal, a first terminal and a second terminal. The first terminal (emitter) of the second transistor **153** is coupled to the second power rail **V2** through the second terminal **T2** of the DSCR device **150**. The second terminals (collector) of the first transistor **151** and the second terminal (collector) of the second transistor **153** are connected together forming the triggering node, which is coupled to the third terminal **T3** of the DSCR device **150** and to receive the triggering signal **St** that triggers the operation of the DSCR device **150**.

The third transistor **155** of the DSCR device **150**, which is different from the first and second transistors **151**, **153** in transistor type, is a NPN BJT and has a base terminal, a first terminal and a second terminal. The first terminal (emitter or collector) of the third transistor **155** is connected to the base terminal of the second transistor **153**. The second terminal (collector or emitter) of the third transistor **155** is connected to the base terminal of the first transistor **151**. In addition, the base terminal of the third transistor **155** is connected to the triggering node commonly joint by the first and second transistors **151**, **153**. It should be noted that the base and emitter terminals of the first transistor **151** are short-circuited (not shown in FIG. 1) in a metal layer, and there is a resistor foamed in an N-well region between the base and emitter terminals of the first transistor **151**. Similarly, the base and emitter terminals of the second transistor **153** are short-circuited (not shown in FIG. 1) in the metal layer, and there is a resistor formed in the other N-well region between the base and emitter terminals of the second transistor **153**. These transistors formed in the well regions are not illustrated in FIG. 1. This relationship would become more comprehensive at the illustration of the structure of the DSCR device later.

In the preset embodiment, when the ESD stress is being applied to the first power rail **V1** (or the second power rail **V2**), the detection circuit **110** would detect the ESD stress and output the detection signal **Sd** to the triggering circuit **130**; then, the triggering circuit **130** outputs the triggering signal **St** to the triggering node of the DSCR device **150** according to the detection signal **Sd**. Based on the ESD stress and the triggering signal, the DSCR device **150** can discharge the ESD stress.

FIG. 2A is an equivalent circuit diagram illustrating an ESD protection circuit **200** according to one of the embodiments of the disclosure. With reference to FIG. 2A, the ESD protection circuit **200** includes a detection circuit **210**, a triggering circuit **230**, and the DSCR device **150**.

In the embodiment, the detection circuit **210** includes a first resistor **211**, a second resistor **213**, and a capacitor **215**, where the first resistor **211**, and the capacitor **215**, and the second resistor **213** are connected in series forming a RCR (resistor-capacitor-resistor) network and coupled between the first and second power rails **V1**, **V2**. The capacitor **215** is coupled to the first power rail **V1** through the first resistor **211** and to the second power rail **V2** through the second resistor **213**. A common node N_{G1} commonly jointed by the first resistor **211** and the capacitor **215** (also referred to as a first node) is coupled to the triggering circuit **230**, and the other common node N_{G2} commonly jointed by the second resistor **213** and the capacitor **215** (also referred to as a second node) is also coupled to the triggering circuit **230**.

The triggering circuit **230** includes a first transistor **231** and a second transistor **233**. The first transistor **231** and the second transistor **233** are connected in series and coupled between the first power rail **V1** and the second power rail **V2**. In the embodiment, the first transistor **231** and the second transistor **233** may be p-type, such as p-type metal-oxide semiconductor (MOS) transistors.

In detail, a first terminal (source) of the first transistor **231** is coupled to the first power rail **V1**, and a control terminal (gate) of the first transistor **231** is coupled to the common node N_{G1} of the detection circuit **210**. On the other end, a first terminal (source) of the second transistor **233** is coupled to the second power rail **V2**, and a control terminal (gate) of the second transistor **233** is coupled to the common node N_{G2} of the detection circuit **210**. The detection circuit **210** generates a first detection signal **Sd1** and a second detection signal **Sd2** as gate voltages for the first transistor **231** and the second transistor **233**, when a ESD stress occurs on the rail **V1** or **V2**. The second terminal (drain) of the first transistor **231** and the second terminal (drain) of the second transistor **233** are coupled to the triggering node (or said third terminal **T3**) of the DSCR device **150**.

In the normal circuit operation, there is no current through the R-C-R path of the detection unit **210** and there is no voltage drop across the first resistor **211** or the second resistor **213**, so that the p-type transistors **231** and **233** have $V_{SG}=0V$. In such a condition, the detection circuit **210** would keep the first and second transistors **231**, **233** of the triggering circuit **230** off, and as a result, no current flows through any of the first transistor **231** and the second transistor **233** and no triggering current would be provided to the triggering node of the DSCR device **150**.

Different from the normal circuit operation, when the ESD stress is applied to the first or second power rail **V1**, **V2**, the detection circuit **210** would turn on the appropriate transistor of the triggering circuit **230** to trigger the DSCR device **150**. For example, when a positive ESD stress V_{ESD} is applied to the first power rail **V1**, an ESD current would flow from the first power rail **V1** to the second power rail **V2**. Initially, the initial voltages at the first node N_{G1} and the second node N_{G2} of the detection circuit **210** are approximate to a half of the ESD voltage ($V_{ESD}/2$), and the voltage across the capacitor **215** is initially 0V. With the ESD current flowing, the capacitor **215** would be charged through the first resistor **211** with a time constant equal to 2RC, and the voltage of the first node N_{G1} increases exponentially and the voltage of the second node N_{G2} decreases exponentially. The voltage drop V_{SG1} across the first resistor **211** is positive and would turn on the first transistor **231** of the triggering circuit **230**, such that the first transistor **231** conduct a current (i.e., the triggering signal **St**) to trigger the DSCR device **150**. At the same time, the voltage drop V_{SG2} across the second resistor **211** is negative and would not be in condition to turn on the second transistor **233**, and thus the second transistor **233** would be off.

Similarly, when a positive ESD stress is applied to the second power rail **V2**, the initial voltages at the first node N_{G1} and the second node N_{G2} of the detection circuit **210** are approximate to a half of the ESD voltage ($V_{ESD}/2$), and the voltage across the capacitor **215** is initially 0V. With the ESD current flowing, the capacitor **215** would be charged and the voltage of the second node N_{G2} increases exponentially and the voltage of the first node N_{G1} decreases exponentially. The voltage drop V_{SG2} across the second resistor **213** is positive and would turn on the second transistor **233** to conduct a current to trigger the DSCR device **150**. At the

same time, the voltage drop V_{SG1} across the first resistor **211** is negative and would not turn on the first transistor **231**.

In the case of negative ESD stress, when a negative ESD stress is applied to the first power rail **V1**, the voltage drop V_{SG1} is negative and would not turn on the first transistor **231** and the voltage drop V_{SG2} is positive and would turn on the second transistor **233**, which conducts a triggering current (i.e., the triggering signal **St**) to trigger the DSCR device **150**. Otherwise, when a negative ESD stress is applied to the second power rail **V2**, the voltage drop V_{SG1} is positive and would turn on the first transistor **231**, such that the first transistor **231** conducts a triggering current to trigger the DSCR device **150**; and at the same time, the voltage drop V_{SG2} is negative and would not turn on the second transistor **233**.

Based on the detection signals **Sd1**, **Sd2** (as gate voltages of the first and second transistor **231**, **233**), the first or second transistor **231**, **233** of the triggering circuit **230** would conduct the ESD current (i.e., triggering signal **St**) to the DSCR device **150** through a common node of the first and second transistors **231**, **233**. The DSCR device **150** is then enabled to provide a path to discharge the positive ESD stress being applied on one power rail (**V1** or **V2**) to the other power rail (**V2** or **V1**). In detail, the transistor **155** of DSCR device **150** would be turned on in response to the triggering signal **St**. Then, the conduction of the transistor **155** would turn on the transistors **151**, **153**, which forms a path directing the ESD stress from one power rail to the other power rail through the transistors **151**, **153**, **155**.

The disclosure provides effective way to detect the ESD stresses which symmetrically triggers the DSCR device to discharge the ESD stresses from the first power rail to the second power rail, or from the second power rail to the first power rail. The embodiment described above may be implemented in nanoscale manufactured ICs and achieve good ESD robustness while maintaining low standby leakage current and relatively small silicon footprint.

FIG. 2B is an equivalent circuit diagram illustrating an ESD protection circuit **200'** according to one of the embodiments of the disclosure. With reference to FIG. 2B, an ESD protection circuit **200'** includes the detection circuit **210**, a triggering circuit **240**, and a DSCR device **160**. In the present embodiment, the DSCR device **160** is a P-well based DSCR (pDSCR) device instead, which includes two NPN BJTs and one PNP BJT, and the emitters of the two NPN BJTs are connected together forming the triggering node. To trigger the pDSCR device **160**, the triggering circuit **240** includes two n-type transistors **241** and **243** (e.g., NMOS transistors) instead, similar to the role of the p-type transistors **231** and **233** illustrated in FIG. 2A, wherein source terminals of the transistors **241** and **243** are respectively coupled to the power rails **V1** and **V2**, and drain terminals of the transistors **241** and **243** are commonly coupled to the triggering node. In the normal circuit operation, the detection circuit **210** of the ESD protection circuit **200'** would keep the transistors of the triggering circuit **240** off, and no triggering current is provided to the triggering node of the DSCR device **160**.

In the case of positive ESD stress, when a positive ESD stress is applied to the first power rail **V1**, the voltage drop V_{GS1} is negative and would not turn on the transistor **241**, and the voltage drop V_{GS2} is positive and would turn on the transistor **243**, which conducts a triggering current (i.e., the triggering signal **St**) to trigger the DSCR device **160**. Otherwise, when a positive ESD stress is applied to the second power rail **V2**, the voltage drop V_{GS1} is positive and would turn on the transistor **241**, such that the transistor **241**

conducts a triggering current to trigger the DSCR device **160**; and at the same time, the voltage drop V_{GS2} is negative and would not turn on the second transistor **243**.

In the case of negative ESD stress, when a negative ESD stress is applied to the first power rail **V1**, the voltage drop V_{GS1} is positive and would turn on the transistor **241**, which conducts a triggering current (i.e., the triggering signal **St**) to trigger the DSCR device **160**, and at the same time, the voltage drop V_{GS2} is negative and would not turn on the transistor **243**. Otherwise, when a negative ESD stress is applied to the second power rail **V2**, the voltage drop V_{GS1} is negative and would not turn on the transistor **241**, and the voltage drop V_{GS2} is positive and would turn on the second transistor **243**, which conducts a triggering current to trigger the DSCR device **160**.

In the following, the disclosure would be described in term of structure. FIG. 3 is a cross-sectional diagram illustrating a structure layout of an ESD protection circuit **300** according to one of the embodiments of the disclosure. The ESD protection circuit **300** is similar to the ESD protection circuit **200** of FIG. 2A and includes the detection circuit **210**, the triggering circuit **230**, and the DSCR device **150**.

With reference to FIG. 3, the N-well based DSCR (nDSCR) device **150** is implemented with embedded p-type transistors of the triggering circuit **230**, and includes a P-type well region **320**, a first N-type well region **340**, and a second N-type well region **360**. In the embodiment, the first N-type well region **340** includes a first P+-type doped region **341**, a first N+-type doped region **342**, a second P+-type doped region **343**, and a third P+-type doped region **344**. In addition, the second N-type well region **360** includes a fourth P+-type doped region **361**, a second N+-type doped region **362**, a fifth P+-type doped region **363**, and a sixth P+-type doped region **364**.

As mentioned above, the DSCR device **150** may be implemented by N-well based or P-well based DSCR (nDSCR or pDSCR). Similarly, the transistors of the triggering circuit may be implemented by n-type or p-type transistors. Therefore, the doping type of the wells and doping regions specified here (e.g., N-type, P-type, N+-type, P+-type, etc.) are to make the disclosure more comprehensible, however, it is not intended to limit the disclosure. The doping type of the regions are based on the type of the DSCR.

The DSCR device **150** includes a first transistor **151**, a second transistor **153**, and a third transistor **155**. With reference to FIG. 3, the first transistor **151** is formed by the first P+-type doped region **341**, the first N-type well region **340** and the P-type well region **320**. The P+ doped region **341** is a contact region acting as the first terminal (emitter) of the first transistor **151**, the N+ doped region **342** is a contact region acting as the base terminal of the first transistor **151**, and the P+ doped region **321** is a contact region acting as the second terminal (collector) of the first transistor **151**.

The second transistor **153** is formed by the fourth P+-type doped region **361**, the second N-type well region **360**, and the P-type well region **320**. The P+ doped region **361** is a contact region acting as the first terminal (emitter) of the second transistor **153**, the N+ doped region **362** is a contact region acting as the based terminal of the second transistor **153**, and the P+ doped region **321** is a contact region acting as the second terminal (collector) of the second transistor **153**.

The third transistor **155** is formed by the first N-type well region **340**, the P-type well region **320**, and the second N-type well region **360**. The N+ doped region **342** is a

contact region acting as the first terminal (emitter or collector) of the third transistor 155, the P+ doped region 321 is a contact region acting as the base terminal of the third transistor 155, and the N+ doped region 362 is a contact region acting as the second terminal (emitter or collector) of the third transistor 155.

In one of the embodiments of the disclosure, the first and second transistors 231, 233 of the triggering circuit 230 may be implemented on the same substrate as the DSCR device 150. With reference to FIG. 3, the first transistor 231 is disposed on the right side of the DSCR device 150, and the second transistor 233 is disposed on the left side of the DSCR device 150. In the embodiment, a first gate region 345 is disposed on the first N-type well region 340 to act as a control terminal of the first transistor 231, and a second gate region 365 is disposed on the second N-type well region 360 to act as a control terminal of the second transistor 233. The first transistor 231 is formed by the second P+-type doped region 343, the first gate region 345, and the third P+-type doped region 344 in the first N-type well region 340. The second transistor 233 is formed by the fifth P+-type doped region 363, the second gate region 365, and the sixth P+-type doped region 364. It should be noted that the first transistor 231 and the second transistor 233 have different body terminals.

In the disclosure, the turn-on speed of a DSCR device may be further enhanced. FIG. 4 is an equivalent circuit diagram illustrating an ESD protection circuit 400 according to one of the embodiments of the disclosure. The operation of the ESD protection circuit 400 is similar to the ESD protection circuit 200 illustrated in FIG. 2. The difference lies within the addition of a first diode 471 and a second diode 473. In detail, a cathode terminal of the first diode 471 is coupled to the first power rail V1 and a first terminal T1 of the DSCR device 150, and an anode terminal of the first diode 471 is connected to the detection circuit 210 and the triggering circuit 230; a cathode terminal of the second diode 473 is coupled to the second power rail V2 and a second terminal T2 of the DSCR device 150, and an anode terminal of the second diode 473 is connected to the detection circuit 210 and the triggering circuit 230. The base terminal of the first transistor 151 is coupled to the resistor 211 and the first terminal of the first transistor 231, and the base terminal of the second transistor 153 is coupled to the resistor 213 and the first terminal of the second transistor 233.

FIG. 5 is a cross sectional diagram illustrating the ESD protection circuit 400 of FIG. 4. With reference to FIG. 5, a pn junction of the first transistor 151, denoted as a parasitic diode 475, is formed between the P+-type doped region 341 and the N+-type doped region 342, and also a pn junction of the second transistor 153, denoted as a parasitic diode 477, is formed between the P+-type doped region 361 and the N+-type doped region 362. When a positive ESD stress is introduced on the first power rail V1, an ESD current would flow through the parasitic diode 471, the parasitic diode 475, the detection circuit 210 (the resistor 211, the capacitor 215, the resistor 213) then to the second power rail V2. The ESD current cause a voltage drop across the first resistor 211, which turns on the first transistor 231 of the triggering circuit 230. Then, the ESD current flows, from the first power rail V1, through the intrinsic parasitic diode 475, the first transistor 231, and into the triggering node (T3), acting as the triggering signal St, and flows through the base-emitter junction of the third transistor 155, the parasitic diode 477, and to the second power rail V2. The described ESD current path would cause all of the parasitic bipolar transistors to

effectively turn on at the same time, and thus improving the turn on speed of the DSCR device 150. When a positive ESD stress is introduced on the second power rail V2, similar behavior can be derived based on the description above and thus it is not being repeated.

FIG. 6 is a circuit diagram illustrating an ESD protection circuit 600 according to one of the embodiments of the disclosure. For the description and operation of the detection circuit 210 and the DSCR device 150, please refer to the description of FIG. 2A. In the embodiment, in addition to the first and second transistors 231, 233, a triggering circuit 630 further includes a diode 635 and a diode 637 to minimize any leakage current from the transistors 231, 233 due to the gate leakage effect or junction leakage.

In detail, the anode of the diode 635 is connected to the second terminal of the p-type transistor 231, and the cathode of the diode 635 is connected to the triggering node. The anode of the diode 637 is connected to the second terminal of the p-type transistor 233, and the cathode of the diode 637 is connected to the triggering node. In another embodiment using a pDSCR device such as the DSCR device 160 of FIG. 2B, a triggering circuit modified based on the triggering circuit 240 of FIG. 2B may also include a first diode and a second diode to minimize any leakage current. In this case, the cathode of the first diode is connected to the second terminal of the n-type transistor 241, and the anode of the first diode is connected to the triggering node; the cathode of the second diode is connected to the second terminal of the n-type transistor 243, and the anode of the second diode is connected to the triggering node. In another embodiment, one of the diode 635 and the diode 637 may be removed and the function of minimizing leakage current may still exist for only one direction. In still another embodiment, a diode string (i.e., more than one diode) may be coupled between a transistor of the triggering circuit and the triggering node.

FIG. 7 is a circuit diagram illustrating an ESD protection circuit 700 according to one of the embodiments of the disclosure. For the description and operation of the triggering circuit 230 and the DSCR device 150, please refer to the description of FIGS. 1 and 2A. In the embodiment, the capacitor 215 illustrated in FIGS. 2A or 2B may be replaced by a plurality of diode strings 717, and the resistors 211, 213 and the diode strings 717 form a RDR (resistor-diode-resistor) network. The diode strings 717 may be connected in antiparallel manner. Similar to the capacitor 215, the diode strings 717 may be coupled to the first power rail V1 through the first resistor 211 and coupled to the second power rail V2 through the second resistor 213. The number of the diodes in each string may be determined according to the maximum voltages between the first and second power rails V1, V2 during normal circuit operation. Under normal circuit operation, the voltage applied between the first and second power rails V1, V2 will be smaller than a turn-on voltage of a diode string (and the other diode string is reverse-biased), so there would be no current flowing through the resistors 211 and 213, thus the transistor 231 and 233 of the triggering circuit would be turned off. When the ESD stress is applied to the first or second power rail V1, V2 and the ESD voltage is high enough, one of the diode strings is turned on and causes voltage drops across the resistors 211 and 213. Similar to the RCR network described in FIG. 2, the voltage drops across the resistors 211 and 213 would turn on one of the first and second transistors 231 and 233 to trigger the DSCR device 150.

In view of aforementioned description, the disclosure provides an ESD protection circuit coupled between a first power rail or a second power rail, which effectively dis-

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charges any ESD stress occurred on the first or second power rail. The ESD protection circuit utilizes a dual silicon controlled rectifier (DSCR) device with a triggering circuit that symmetrically triggers the DSCR device in response to polarities of the ESD stress. The exemplary ESD protection circuit may be implemented in nanoscale manufactured integrated circuit and achieve good ESD robustness while maintaining low standby leakage current and relatively small silicon footprint.

It will be apparent to those skilled in the art that various modifications and variations can be made to the structure of the present invention without departing from the scope or spirit of the invention. In view of the foregoing, it is intended that the present invention cover modifications and variations of this invention provided they fall within the scope of the following claims and their equivalents.

What is claimed is:

1. An electrostatic discharge (ESD) protection circuit, comprising:

a detection circuit, coupled between a first power rail and a second power rail, detecting an ESD stress from the first power rail or the second power rail, and outputting a detection signal according to the ESD stress;

a triggering circuit, coupled to the detection circuit, receiving the detection signal and outputting a triggering signal according to the detection signal; and

a dual-directional silicon controlled rectifier (DSCR) device, comprising a first terminal coupled to the first power rail, a second terminal coupled to the second power rail, a third terminal coupled to the triggering circuit to receive the triggering signal, and at least two transistors of a first type, and configured to discharge the ESD stress according to the triggering signal, wherein the third terminal is coupled to a common node between at least two transistors of the first type.

2. The ESD protection circuit of claim 1, wherein the at least two transistors of the first type comprise:

a first transistor of the first type, having a base terminal, a first terminal coupled to the first terminal of the DSCR device, and a second terminal; and

a second transistor of the first type, having a base terminal, a first terminal coupled to the second terminal of the DSCR device, and a second terminal coupled to the second terminal of the first transistor of the first type, wherein the common node is formed by the second terminal of the first transistor of the first type and the second terminal of the second transistor of the first type.

3. The ESD protection circuit of claim 2, wherein the DSCR device further comprises:

a third transistor of a second type, having a base terminal coupled to the common node, a first terminal coupled to the base terminal of the second transistor of the first type, and a second terminal coupled to the base of the first transistor of the first type.

4. The ESD protection circuit of claim 3, wherein the first transistor is formed by a first region of a second doping type disposed in a first well of a first doping type, the first well of the first doping type, and a third well of the second doping type,

wherein the second transistor is formed by a second region of the second doping type disposed in a second well of the first doping type, the second well of the first doping type, and the third well of the second doping type, and

wherein the third transistor is formed by the first well of the first doping type, the third well of the second doping

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type disposed between the first well of the first doping type and the second well of the first doping type, and the second well of the first doping type, wherein the common node of the first transistor, the second transistor and the third transistor is formed by the third well.

5. The ESD protection circuit of claim 1, wherein the triggering circuit comprises:

a fourth transistor having a first terminal coupled to the first power rail, a second terminal coupled to the third terminal of the DSCR device, and a control terminal coupled to the detection circuit; and

a fifth transistor, having a first terminal coupled to the second power rail, a second terminal coupled to the second terminal of the fourth transistor, and a control terminal coupled to the detection circuit.

6. The ESD protection circuit of claim 5, wherein the triggering circuit further comprises at least one of:

a first diode coupled between the second terminal of the fourth transistor and the third terminal of the DSCR device; and

a second diode coupled between the first terminal of the fifth transistor and the third terminal of the DSCR device.

7. The ESD protection circuit of claim 5, wherein the detection circuit comprises:

a first resistor, coupled between the first power rail and the control terminal of the fourth transistor of the triggering circuit;

a second resistor, coupled between the second power rail and the control terminal of the fifth transistor of the triggering circuit;

a first capacitor, coupled between the first resistor and the second resistor.

8. The ESD protection circuit of claim 5, wherein the detection circuit comprises:

a first resistor, coupled between the first power rail and the control terminal of the fourth transistor of the triggering circuit;

a second resistor, coupled between the second power rail and the control terminal of the fifth transistor of the triggering circuit;

an anti-parallel diode string, coupled between the first resistor and the second resistor.

9. The ESD protection circuit of claim 1, further comprising:

a third diode, coupled between the first power rail and the detection circuit; and

a fourth diode, coupled between the second power rail and the detection circuit.

10. The ESD protection circuit of claim 1, wherein the DSCR device comprises:

a first well of a first doping type, having a first doped region of a second doping type;

a second well of the first doping type, having a second doped region of the second doping type;

a third well of the second doping type, disposed between the first well of the first doping type and the second well of the first doping type, and having a third doped region of the second doping type with higher doping concentration,

wherein the first doped region of the second doping type is coupled to one of the first terminal and the second terminal of the DSCR device, the second doped region is coupled to another one of the first terminal and the

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second terminal of the DSCR device, and the third doped region is coupled to the third terminal of the DSCR device.

11. An electrostatic discharge (ESD) protection circuit, coupled between a first power rail and a second power rail, comprising:

a switch circuit, outputting a triggering signal in response to an ESD stress from the first power rail or the second power rail;

a first transistor of a first type and a second transistor of the first type connected in series between the first power rail and the second power rail, wherein a common node commonly jointed by first transistor and the second transistor is coupled to the switch circuit for receiving the triggering signal.

12. The ESD protection circuit of claim 11, further comprising:

a third transistor of a second type, having a base terminal coupled to the common node of the first and the second transistors, a first terminal and a second terminal respectively coupled to a base terminal of each of the first and the second transistors.

13. The ESD protection circuit of claim 11, wherein the first transistor of the first type has the base terminal, a first

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terminal coupled to the first power rail, and a second terminal coupled to the switch circuit; and

the second transistor of the first type has the base terminal, a first terminal coupled to the second power rail, and a second terminal coupled the switch circuit.

14. The ESD protection circuit of claim 11, wherein the switch circuit comprises:

a first resistor, coupled to the first power rail;

a second resistor, coupled to the second power rail;

a capacitor, coupled between the first resistor and the second resistor;

a fourth transistor, having a control terminal, a first terminal and a second terminal, the control terminal being coupled to a first node commonly jointed by the first resistor and the capacitor, the first terminal being coupled to the first power rail, and the second terminal coupled to the common node; and

a fifth transistor, having a control terminal, a first terminal and a second terminal, the control terminal being coupled to a third node commonly jointed by the second resistor and the capacitor, the first terminal being coupled to the second power rail, and the second terminal being coupled to the common node.

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