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Electrostatic discharge (ESD) protection circuit and method of operating the same

Abstract

An electrostatic discharge (ESD) protection circuit includes a first and second diode in a semiconductor wafer, an ESD clamp circuit and a first conductive structure on a backside of a semiconductor wafer. The first diode is coupled between an input output (IO) pad and a first node. The second diode is coupled to the first diode, and coupled between the IO pad and a second node. The ESD clamp circuit is in the semiconductor wafer, coupled to the first and second node, and between the first and second diode. The ESD clamp circuit includes a first signal tap region in the semiconductor wafer that is coupled to a reference voltage supply. The second diode is coupled to and configured to share the first signal tap region with the ESD clamp circuit. The first conductive structure is configured to provide a reference voltage to the first signal tap region.

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Background/Summary

PRIORITY CLAIM AND CROSS-REFERENCE (1) The present application is a continuation of U.S. application Ser. No. 18/128,693, filed Mar. 30, 2023, now U.S. Pat. No. 11,862,960, issued Jan. 2, 2024, which is a continuation of U.S. application Ser. No. 17/147,253, filed Jan. 12, 2021, now U.S. Pat. No. 11,626,719, issued Apr. 11, 2023, which claims the benefit of U.S. Provisional Application No. 63/002,562, filed Mar. 31, 2020, which are herein incorporated by reference in their entireties.

BACKGROUND

(1) The recent trend in miniaturizing integrated circuits (ICs) has resulted in smaller devices which consume less power, yet provide more functionality at higher speeds than before. The miniaturization process has also increased the devices' susceptibility to electrostatic discharge (ESD) events due to various factors, such as thinner dielectric thicknesses and associated lowered dielectric breakdown voltages. ESD is one of the causes of electronic circuit damage and is also one of the considerations in semiconductor advanced technology.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) Aspects of the present disclosure are best understood from the following detailed description when read with the accompanying figures. It is noted that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

(2) FIG. 1 is a schematic block diagram of an integrated circuit, in accordance with some embodiments.

(3) FIG. 2 is a schematic block diagram of an integrated circuit, in accordance with some embodiments.

- (4) FIG. 3A is a cross-sectional view of an integrated circuit, in accordance with some embodiments.
- (5) FIG. 3B is a cross-sectional view of an integrated circuit, in accordance with some embodiments.
- (6) FIG. 4 is a cross-sectional view of an integrated circuit, in accordance with some embodiments.
- (7) FIG. 5 is a flowchart of a method of operating an ESD circuit, in accordance with some embodiments.
- (8) FIG. 6 is a flowchart of a method of manufacturing an ESD circuit, in accordance with some embodiments.
- (9) FIGS. 7A-7E are cross-sectional views of an integrated circuit, in accordance with one or more embodiments.

DETAILED DESCRIPTION

(10) The following disclosure provides different embodiments, or examples, for implementing features of the provided subject matter. Specific examples of components, materials, values, steps, arrangements, or the like, are described below to simplify the present disclosure. These are, of course, merely examples and are not limiting. Other components, materials, values, steps, arrangements, or the like, are contemplated. For example, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed between the first and second features, such that the first and second features may not be in direct contact. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed.

(11) Further, spatially relative terms, such as “beneath,” “below,” “lower,” “above,” “upper” and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. The spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. The apparatus may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein may likewise be interpreted accordingly.

(12) In some embodiments, an ESD protection circuit includes a first diode, a second diode and an ESD clamp circuit. The first diode is in a semiconductor wafer, and is coupled to an input output (IO) pad. The second diode is in the semiconductor wafer, and is coupled to the first diode and the IO pad. The ESD clamp circuit is in the semiconductor wafer, and is coupled to the first diode and the second diode. The ESD clamp circuit includes a first signal tap region and a second signal tap region in the semiconductor wafer. The first signal tap region is coupled to a first voltage supply. The second signal tap region is coupled to a second voltage supply different from the first voltage supply.

(13) The first diode is coupled to and configured to share the first signal tap region with the ESD clamp circuit. The second diode is coupled to and configured to share the second signal tap region with the ESD clamp circuit. In some embodiments, by the first diode sharing the first signal tap region with the ESD clamp circuit, and by the second diode sharing the second signal tap region with the ESD clamp circuit, the ESD protection circuit of the present disclosure occupies less area than other approaches.

(14) In some embodiments, by the first diode sharing the first signal tap region with the ESD clamp circuit, and by the second diode sharing the second signal tap region with the ESD clamp circuit, the ESD protection circuit of the present disclosure has less signal taps than other approaches resulting in the ESD protection circuit of the present disclosure having less resistance than other approaches. In some embodiments, by having less resistance than other approaches, the ESD

protection circuit of the present disclosure has a lower clamping voltage and is faster in operation than other approaches.

(15) FIG. 1 is a schematic block diagram of an integrated circuit **100**, in accordance with some embodiments.

(16) Integrated circuit **100** comprises an internal circuit **102**, a voltage supply node **104**, a reference voltage supply node **106**, an input/output (IO) pad **108**, a diode D1, a diode D2, an IO circuit **110** and an ESD clamp circuit **120**. In some embodiments, at least integrated circuit **100**, **200** (FIG. 2) or **300A-300B** (FIGS. 3A-3B) is incorporated on a single integrated circuit (IC), or on a single semiconductor substrate. In some embodiments, at least integrated circuit **100**, **200** (FIG. 2) or **300A-300B** (FIGS. 3A-3B) includes one or more ICs incorporated on one or more single semiconductor substrates.

(17) Internal circuit **102** is coupled to the IO circuit **110**. In some embodiments, internal circuit **102** is further coupled to IO pad **108**, diode D1 and diode D2. Internal circuit **102** is configured to receive an IO signal from IO pad **108** through IO circuit **110**. In some embodiments, internal circuit **102** is coupled to voltage supply node **104** (e.g. VDD) and reference voltage supply node **106** (e.g., VSS). In some embodiments, internal circuit **102** is configured to receive a supply voltage VDD from voltage supply node **104** (e.g. VDD), and a reference supply voltage VSS from reference voltage supply node **106** (e.g., VSS).

(18) Internal circuit **102** includes circuitry configured to generate or process the IO signal received by or output to IO pad **108**. In some embodiments, internal circuit **102** comprises core circuitry configured to operate at a voltage lower than supply voltage VDD of voltage supply node **104**. In some embodiments, internal circuit **102** includes at least one n-type or p-type transistor device. In some embodiments, internal circuit **102** includes at least a logic gate cell. In some embodiments, a logic gate cell includes an AND, OR, NAND, NOR, XOR, INV, AND-OR-Invert (AOI), OR-AND-Invert (OAI), MUX, Flip-flop, BUFF, Latch, delay, or clock cells. In some embodiments, internal circuit **102** includes at least a memory cell. In some embodiments, the memory cell includes a static random access memory (SRAM), a dynamic RAM (DRAM), a resistive RAM (RRAM), a magnetoresistive RAM (MRAM) or read only memory (ROM). In some embodiments, internal circuit **102** includes one or more active or passive elements.

(19) Examples of active elements include, but are not limited to, transistors and diodes. Examples of transistors include, but are not limited to, metal oxide semiconductor field effect transistors (MOSFET), complementary metal oxide semiconductor (CMOS) transistors, bipolar junction transistors (BJT), high voltage transistors, high frequency transistors, p-channel and/or n-channel field effect transistors (PFETs/NFETs), FinFETs, and planar MOS transistors with raised source/drain. Examples of passive elements include, but are not limited to, capacitors, inductors, fuses, and resistors.

(20) Voltage supply node **104** is coupled to diode D1 and ESD clamp circuit **120** at node Nd1. Reference voltage supply node **106** is coupled to diode D2 and ESD clamp circuit **120** at node Nd2. Voltage supply node **104** is configured to receive supply voltage VDD for normal operation of internal circuit **102**. Similarly, reference voltage supply node **106** is configured to receive reference supply voltage VSS for normal operation of internal circuit **102**. In some embodiments, at least voltage supply node **104** is a voltage supply pad. In some embodiments, at least reference voltage supply node **106** is a reference voltage supply pad. In some embodiments, a pad is at least a conductive surface, a pin, a node or a bus. Voltage supply node **104** or reference voltage supply node **106** is also referred to as a power supply voltage bus or rail. In the example configuration in FIG. 1, 2 or 3A-3B, supply voltage VDD is a positive supply voltage, voltage supply node **104** is a positive power supply voltage, reference supply voltage VSS is a ground supply voltage, and reference voltage supply node **106** is a ground voltage terminal. Other power supply arrangements are within the scope of the present disclosure.

(21) IO pad **108** is coupled to IO circuit **110** by a node Nd3. IO pad **108** is coupled to internal

circuit **102** by IO circuit **110**. In some embodiments, IO circuit **110** is not included in integrated circuit **100**, and IO pad is coupled to internal circuit **102** directly. IO pad **108** is configured to receive IO signal from IO circuit **110** or configured to output IO signal to IO circuit **110**. IO pad **108** is at least a pin that is coupled to IO circuit **110** or internal circuit **102**. In some embodiments, IO pad **108** is a node, a bus or a conductive surface that is coupled to IO circuit **110** or internal circuit **102**.

(22) Diode D1 is coupled between voltage supply node **104** and IO pad **108**. Diode D1 is coupled between node Nd1 and node Nd3. An anode of diode D1 is coupled to node Nd3, IO circuit **110**, IO pad **108** and a cathode of diode D2. A cathode of diode D1 is coupled to voltage supply node **104**, ESD clamp circuit **120** and node Nd1. In some embodiments, the cathode of diode D1 is coupled to ESD clamp circuit **120** by node Nd1. In some embodiments, diode D1 is a pull-up diode or referred to as a p+ diode. For example, in these embodiments, the p+-diode is formed between a p-well region (e.g., well **322** of FIGS. 3A-3B) and an n-well region (not shown), and the n-well region is connected to VDD (See FIGS. 3A-3B). In some embodiments, diode D1 is a vertical well diode. Other diode types for diode D1 are within the scope of the present disclosure.

(23) Diode D2 is coupled between reference voltage supply node **106** and IO pad **108**. Diode D2 is coupled between node Nd3 and node Nd2. An anode of diode D2 is coupled to reference voltage supply node **106**, ESD clamp circuit **120** and node Nd2. A cathode of diode D2 is coupled to node Nd3, IO circuit **110**, IO pad **108** and the anode of diode D1. In some embodiments, diode D2 is a pull-down diode or referred to as an n+ diode. For example, in these embodiments, the n+-diode is formed between an n-well region (e.g., well **332** of FIGS. 3A-3B) and a p-well (not shown), and the P-substrate is connected to ground or VSS. In some embodiments, diode D2 is a vertical well diode. Other diode types for diode D2 are within the scope of the present disclosure.

(24) Diodes D1 and D2 are configured to have a minimal impact on the normal behavior (e.g., no ESD conditions or events) of internal circuit **102** or integrated circuit **100**. In some embodiments, an ESD event occurs when an ESD voltage or current higher than a level of voltage or current expected during the normal operation of internal circuit **102** is applied to at least voltage supply node **104**, reference voltage supply node **106** or IO pad **108**.

(25) When no ESD events occur, diodes D1 and D2 do not affect the operation of integrated circuit **100**. During an ESD event, diode D1 is configured to transfer voltage or current between voltage supply node **104** and IO pad **108** dependent upon whether diode D1 is forward biased or reverse biased, and the voltage levels of the voltage supply node **104** and IO pad **108**.

(26) For example, during a Positive-to-VDD (PD) mode of ESD stress or event, diode D1 is forward biased and is configured to transfer voltage or current from IO pad **108** to voltage supply node **104**. In PD-mode, a positive ESD stress or ESD voltage (at least greater than supply voltage VDD) is applied to IO pad **108**, while voltage supply node **104** (e.g., VDD) is ground and reference voltage supply node **106** (e.g., VSS) is floating.

(27) For example, during a Negative-to-VDD (ND) mode of ESD stress or event, diode D1 is reverse biased and is configured to transfer voltage or current from voltage supply node **104** to IO pad **108**. In ND-mode, a negative ESD stress is received by IO pad **108**, while the voltage supply node **104** (e.g., VDD) is ground and reference voltage supply node **106** (e.g., VSS) is floating.

(28) During an ESD event, diode D2 is configured to transfer voltage or current between reference voltage supply node **106** and IO pad **108** dependent upon whether diode D2 is forward biased or reverse biased, and the voltage levels of the reference voltage supply node **106** and IO pad **108**.

(29) For example, during a Positive-to-VSS (PS) mode of ESD stress or event, diode D2 is reverse biased and is configured to transfer voltage or current from IO pad **108** to reference voltage supply node **106**. In PS-mode, a positive ESD stress or ESD voltage (at least greater than reference supply voltage VSS) is applied to IO pad **108**, while voltage supply node **104** (e.g., VDD) is floating and reference voltage supply node **106** (e.g., VSS) is ground.

(30) For example, during a Negative-to-VSS (NS) mode of ESD stress or event, diode D2 is

forward biased and is configured to transfer voltage or current from reference voltage supply node **106** to IO pad **108**. In NS-mode, a negative ESD stress is received by IO pad **108**, while the voltage supply node **104** (e.g., VDD) is floating and reference voltage supply node **106** (e.g., VSS) is ground.

(31) Other types of diodes, configurations and arrangements of at least diode **D1** or **D2** are within the scope of the present disclosure.

(32) IO circuit **110** is coupled to IO pad **108**, internal circuit **102**, diodes **D1** and **D2** and node **Nd3**. IO circuit is coupled between node **Nd3** and internal circuit **102**. In some embodiments, IO circuit is an IO buffer configured to buffer signals sent to or from internal circuit **102**. In some embodiments, IO circuit **110** includes at least the logic gate cell described above. Other types of circuits, configurations and arrangements of IO circuit **110** are within the scope of the present disclosure.

(33) ESD clamp circuit **120** is coupled between voltage supply node **104** (e.g. supply voltage VDD) and reference voltage supply node **106** (e.g., VSS). ESD clamp circuit **120** is coupled between node **Nd1** and node **Nd2**. ESD clamp circuit **120** is coupled to diode **D1** by node **Nd1**. ESD clamp circuit **120** is coupled to diode **D2** by node **Nd2**.

(34) When no ESD event occurs, ESD clamp circuit **120** is turned off. For example, when no ESD event occurs, ESD clamp circuit **120** is turned off, and is therefore a nonconductive device or circuit during the normal operation of internal circuit **102**. In other words, ESD clamp circuit **120** is turned off or is non-conductive in the absence of an ESD event.

(35) If an ESD event occurs, ESD clamp circuit **120** is configured to sense the ESD event, and is configured to turn on and provide a current shunt path between voltage supply node **104** (e.g. supply voltage VDD) or node **Nd1** and reference voltage supply node **106** (e.g., VSS) or node **Nd2** to thereby discharge the ESD current. For example, when an ESD event occurs, the voltage difference across the ESD clamp circuit **120** is equal to or greater than a threshold voltage of ESD clamp circuit **120**, and ESD clamp circuit **120** is turned on thereby conducting current between voltage supply node **104** (e.g. VDD) and reference voltage supply node **106** (e.g., VSS).

(36) During an ESD event, ESD clamp circuit **120** is configured to turn on and discharge an ESD current in a forward ESD direction (e.g., current **I1a**) from the reference voltage supply node **106** (e.g., VSS) to the voltage supply node **104** (e.g. VDD). Current **I1a** is shown in FIG. 1 between node **Nd2** to node **Nd1** for simplicity, but it is understood that current **I1a** is from the reference voltage supply node **106** (e.g., VSS) to the voltage supply node **104** (e.g. VDD).

(37) During an ESD event, ESD clamp circuit **120** is configured to turn on and discharge an ESD current in a reverse ESD direction (e.g., current **I2a**) from the voltage supply node **104** (e.g. VDD) to the reference voltage supply node **106** (e.g., VSS). Current **I2a** is shown in FIG. 1 between node **Nd1** to node **Nd2** for simplicity, but it is understood that current **I2a** is from the voltage supply node **104** (e.g. VDD) to the reference voltage supply node **106** (e.g., VSS).

(38) During a positive ESD surge on reference voltage supply node **106**, ESD clamp circuit **120** is configured to turn on and discharge the ESD current **I1a** in a forward ESD direction from the reference voltage supply node **106** (e.g., VSS) to the voltage supply node **104** (e.g. VDD). In some embodiments, ESD clamp circuit **120** is configured to turn on, after a PS mode (described above) of ESD, and discharge the ESD current **I1** in the forward ESD direction from node **Nd3** to node **Nd2**, and from node **Nd2** to the voltage supply node **104** (e.g. VDD) by node **Nd1**.

(39) During a positive ESD surge on voltage supply node **104**, ESD clamp circuit **120** is configured to turn on and discharge the ESD current **I2a** in a reverse ESD direction from voltage supply node **104** (e.g. VDD) to reference voltage supply node **106** (e.g., VSS). In some embodiments, ESD clamp circuit **120** is configured to turn on, after a PD mode (described above) of ESD, and discharge the ESD current **I2** in the reverse ESD direction from node **Nd3** to node **Nd1**, and from node **Nd1** to the reference voltage supply node **106** (e.g., VSS) by node **Nd2**.

(40) In some embodiments, ESD clamp circuit **120** is a transient clamp. For example, in some

embodiments, ESD clamp circuit **120** is configured to handle transient or ESD events, e.g., rapid changes in voltage and/or current from the ESD event. During the transient or ESD, the ESD clamp circuit **120** is configured to turn on to provide a shunt path between voltage supply node **104** (e.g., supply voltage VDD) and reference voltage supply node **106** (e.g., VSS) before the ESD event can cause damage to one or more elements within integrated circuit **100**. In some embodiments, ESD clamp circuit **120** is configured to turn off slower than it turns on.

(41) In some embodiments, ESD clamp circuit **120** is a static clamp. In some embodiments, static clamps are configured to provide a static or steady-state voltage and current response. For example, static clamps are turned-on by a fixed voltage level.

(42) In some embodiments, ESD clamp circuit **120** includes a large NMOS transistor configured to carry the ESD current without entering the avalanche breakdown region of the ESD clamp circuit **120**. In some embodiments, ESD clamp circuit **120** is implemented without having avalanching junctions inside ESD clamp circuit **120**, and is also known as a “non-snapback protection scheme.”

(43) Other types of clamp circuits, configurations and arrangements of ESD clamp circuit **120** are within the scope of the present disclosure.

(44) Other configurations or quantities of circuits in integrated circuit **100** are within the scope of the present disclosure.

(45) FIG. 2 is a schematic block diagram of an integrated circuit **200**, in accordance with some embodiments.

(46) Integrated circuit **200** is an embodiment of integrated circuit **100**, and similar detailed description is therefore omitted. For example, integrated circuit **200** includes at least a portion of integrated circuit **100** included as part of a substrate **202**. While integrated circuit **200** of FIG. 2 shows a portion of integrated circuit **100**, it is understood that integrated circuit **200** can be modified to include each of the features of integrated circuit **100**, and similar detailed description is therefore omitted for brevity.

(47) Components that are the same or similar to those in one or more of FIGS. 1, 2, 3A-3B and 4 (shown below) are given the same reference numbers, and detailed description thereof is thus omitted.

(48) Integrated circuit **200** includes voltage supply node **104**, reference voltage supply node **106**, IO pad **108**, diode D1, diode D2, substrate **202** and a clamp circuit **220**.

(49) Integrated circuit **200** is a variation of integrated circuit **100** of FIG. 1, and similar detailed description is therefore omitted. In comparison with integrated circuit **100**, ESD clamp circuit **220** replaces ESD clamp circuit **120** of FIG. 1, and similar detailed description is therefore omitted.

(50) ESD clamp circuit **220** are formed on substrate **202**. Substrate **202** extends in a first direction X. Substrate **202** has a backside **203** and a front side **205** opposite from the backside **203** in a second direction Y. In some embodiments, the second direction Y is different from the first direction X. In some embodiments, a bulk of substrate **202** has been removed during wafer thinning. In some embodiments, substrate **202** is part of a super power rail (SPR) technology or process. In some embodiments, substrate **202** is a silicon on insulator (SOI) technology or process. In some embodiments, at least diode D1 or D2 is formed on substrate **202**. Other types of substrate technology or processes for substrate **202** are within the scope of the present disclosure.

(51) ESD clamp circuit **220** includes a signal tap **250** and a signal tap **252**.

(52) In some embodiments, at least signal tap **252** corresponds to a well tap. In some embodiments, a well tap is an electrically conductive lead that couples a well region (shown in FIG. 3A-3B) of substrate **202** to voltage supply node **104** (e.g., supply voltage VDD). For example, in some embodiments, the well region includes a heavily doped n-region in an n-type well on a p-type substrate. In some embodiments, the heavily doped n-region is coupled through the well tap to voltage supply node **104** (e.g., supply voltage VDD) thereby setting the potential of the n-type well to prevent leakage from adjacent source/drain regions into the well.

(53) In some embodiments, at least signal tap **250** corresponds to a substrate tap. In some

embodiments, a substrate tap is an electrically conductive lead that couples a region of substrate **202** to reference voltage supply node **106** (e.g., reference supply voltage VSS). For example, in some embodiments, the region of substrate **202** includes a heavily doped p-region which is formed in a p-type substrate. In some embodiments, the heavily doped p-region is coupled through the substrate tap to the reference voltage supply node **106** (e.g., reference supply voltage VSS) thereby setting the potential of the substrate **202** to prevent leakage from adjacent source/drain regions.

(54) Through the use of signal taps **250** and **252** the resistance of substrate **202** and undesirable positive feedback in integrated circuit **200** are reduced. In some embodiments, at least signal tap **250** or **252** is configured to limit a resistance between power or ground connections to wells (shown in FIGS. **3A-3B**) of substrate **202**. In some embodiments, the use of at least signal tap **250** or **252** results in less drift in substrate **202** thereby preventing latch-up effects.

(55) Signal tap **250** is coupled to the voltage supply node **104** (e.g., voltage VDD) on the backside **203** of substrate **202**. Signal tap **250** is further coupled to the cathode of diode **D1**.

(56) Signal tap **252** is coupled to the reference voltage supply node **106** (e.g., voltage VSS) on the backside **203** of substrate **202**. Signal tap **252** is further coupled to the anode of diode **D2**.

(57) IO pad **108** is on the backside **203** of substrate **202**, and is coupled to the anode of diode **D1** and the cathode of diode **D2**. In some embodiments, integrated circuit **200** is electrically connected to one or more other package structures (not shown) on the backside **203** of substrate **202**.

(58) In some embodiments, diode **D1** is configured to share signal tap **250** with ESD clamp circuit **220**, and diode **D2** is configured to share signal tap **252** with ESD clamp circuit **220**. In some embodiments, by sharing signal tap **250** with ESD clamp circuit **220**, diode **D1** does not include a signal tap resulting in integrated circuit **200** occupying less area than other approaches. In some embodiments, by sharing signal tap **252** with ESD clamp circuit **220**, diode **D2** does not include a signal tap resulting in integrated circuit **200** occupying less area than other approaches.

(59) By at least diode **D1** or **D2** not including corresponding signal taps, integrated circuit **200** has less resistance since integrated circuit **200** includes fewer signal taps than other approaches.

(60) Other types of clamp circuits, configurations and arrangements of ESD clamp circuit **120** are within the scope of the present disclosure.

(61) Other configurations or quantities of circuits in integrated circuit **200** are within the scope of the present disclosure.

(62) FIG. **3A** is a cross-sectional view of an integrated circuit **300A**, in accordance with some embodiments.

(63) Integrated circuit **300A** is an embodiment of at least integrated circuit **100** of FIG. **1** or integrated circuit **200** of FIG. **2**, and similar detailed description is therefore omitted.

(64) While FIGS. **3A-3B** are described with respect to a portion of integrated circuit **100** of FIG. **1** or integrated circuit **200** of FIG. **2**, the teachings of FIGS. **3A-3B** are also applicable to other portions of integrated circuit **100** or **200** (not described with respect to at least FIGS. **3A-3B**), and similar detailed description is therefore omitted for brevity.

(65) Integrated circuit **300A** includes a diode **302**, a diode **304**, an ESD clamp circuit **310** and a substrate **320**.

(66) Diode **302** is an embodiment of diode **D1** of FIGS. **1-2**, diode **304** is an embodiment of diode **D2** of FIGS. **1-2**, ESD clamp circuit **310** is an embodiment of ESD clamp circuit **120** of FIG. **1** or **210** of FIG. **2**, and substrate **320** is an embodiment of substrate **202** of FIG. **2**, and similar detailed description is therefore omitted.

(67) At least diode **302**, diode **D2** or ESD clamp circuit **310** is formed on substrate **320**. In some embodiments, at least diode **302**, diode **D2** or ESD clamp circuit **310** is formed on a front side **305** of substrate **320**.

(68) Substrate **320** has a front side **305** and a backside **303** opposite from the front side **305** in a second direction **Y**. Substrate **320** has a side **326** and a side **336** opposite from side **326** in the first direction **X**. In some embodiments, a bulk of substrate **320** has been removed during wafer

thinning. In some embodiments, substrate **320** is part of a super power rail (SPR) technology or process. In some embodiments, substrate **320** is a silicon on insulator (SOI) technology or process. In some embodiments, substrate **320** is also referred to as a wafer. In some embodiments, substrate **320** includes an insulating layer **321**. Insulating layer **321** is between the back-side **303** and front-side **305** of substrate **320**. In some embodiments, the insulating layer **321** is a non-conducting oxide material. In some embodiments, the insulating layer **321** is formed on the back-side **303** of substrate **320** after wafer thinning and oxide regrowth. In some embodiments, the front-side **305** and the back-side **303** are electrically isolated from each other by at least the insulating layer **321**. In some embodiments, the insulating layer **321** includes a dielectric material including oxide or another suitable insulating material.

(69) Substrate **320** is a p-type substrate. In some embodiments, substrate **320** is an n-type substrate. In some embodiments, substrate **320** includes an elemental semiconductor including silicon or germanium in crystal, polycrystalline, or an amorphous structure; a compound semiconductor including silicon carbide, gallium arsenic, gallium phosphide, indium phosphide, indium arsenide, and indium antimonide; an alloy semiconductor including SiGe, GaAsP, AlInAs, AlGaAs, GaInAs, GaInP, and GaInAsP; any other suitable material; or combinations thereof. In some embodiments, the alloy semiconductor substrate has a gradient SiGe feature in which the Si and Ge composition change from one ratio at one location to another ratio at another location of the gradient SiGe feature. In some embodiments, the alloy SiGe is formed over a silicon substrate. In some embodiments, substrate **320** is a strained SiGe substrate. In some embodiments, the semiconductor substrate has a semiconductor on insulator structure, such as a silicon on insulator (SOI) structure. In some embodiments, the semiconductor substrate includes a doped epi layer or a buried layer. In some embodiments, the compound semiconductor substrate has a multilayer structure, or the substrate includes a multilayer compound semiconductor structure.

(70) Diode **302** includes an anode **302a**, a gate structure **302b**, a cathode **302c**, a cathode **302d**, a channel region **302e** and a well **322**. Diode **302** is a vertical well diode. In some embodiments, diode **302** is a nanosheet vertical well diode. In some embodiments, diode **302** is formed on a front side **305** of substrate **320**. Other diode types for diode **302** are within the scope of the present disclosure.

(71) Diode **302** corresponds to diode D1 of FIGS. 1-2, and similar detailed description is omitted. Anode **302a** corresponds to the anode of diode D1 of FIGS. 1-2, cathodes **302c** and **302d** corresponds to the cathode of diode D1 of FIGS. 1-2, and the channel region **302e** corresponds to a channel region of diode D1, and similar detailed description is omitted.

(72) Well **322** is formed in substrate **320**. Well **322** has p-type dopant impurities and is referred to as a P-type well. In some embodiments, well **322** has n-type dopant impurities and is referred to as an N-type well.

(73) Well **322** includes a region **324**. Region **324** is embedded in well **322**. Region **324** is a heavily doped p-region. In some embodiments, region **324** is a heavily doped n-region.

(74) The anode **302a** includes well **322** and region **324**. The anode **302a** is a P-type active region having P-type dopants in well **322**.

(75) The cathode **302c** is an N-type active region having N-type dopants and is located on well **322**. The cathode **302d** is an N-type active region having N-type dopants and is located on well **322**. In some embodiments, at least cathode **302c** or **302d** is a P-type active region having P-type dopants. The cathode **302c** and the cathode **302d** are separated from each other in the first direction X. In some embodiments, cathode **302c** and cathode **302d** are corresponding cathodes of two diodes coupled together in parallel. Integrated circuits **300A-300B** are shown with two cathodes (e.g., cathodes **302c** and **302d**) and a single anode (e.g., anode **302a**). Other number of cathodes **302c** or **302d** and/or anodes **302a** are within the scope of the present disclosure.

(76) The anode **302a** and the cathode **302c** together form a PN junction, and the anode **302a** and the cathode **302d** together form another PN junction. In some embodiments, at least cathode **302c**

or cathode **302d** extends above substrate **320**. In some embodiments, at least a top surface of cathode **302c** or a top surface of cathode **302d** is flush with the front side **305** of substrate **320**.

(77) The gate structure **302b** is at least partially over well **322**, and in between cathode **302c** and cathode **302d**. In some embodiments, the gate structure **302b** is electrically floating. In some embodiments, the gate structure **302b** is electrically coupled to cathodes **302c** and **302d**. The channel region **302e** couples the cathode **302c** and the cathode **302d**. In some embodiments, the channel region **302e** is in well **322**.

(78) In some embodiments, diode **302** does not include a signal tap region. In some embodiments, diode **302** is configured to share a signal tap region **350** with ESD clamp circuit **310**. For example, in some embodiments, diode **302** is electrically coupled to the signal tap region **350** of ESD clamp circuit **310** by at least a conductive structure **390**. In some embodiments, by sharing signal tap region **350** with ESD clamp circuit **310**, integrated circuit **300A** or **300B** occupies less area than other approaches. In some embodiments, by sharing signal tap region **350** with ESD clamp circuit **310**, integrated circuit **300A** or **300B** has less signal taps than other approaches resulting in integrated circuit **300A** or **300B** having less resistance than other approaches, and simpler routing.

(79) Other types of circuits, configurations and arrangements of diode **302** are within the scope of the present disclosure.

(80) Diode **304** includes an anode **304a**, a gate structure **304b**, a cathode **304c**, a cathode **304d**, a channel region **304e** and a well **332**. Diode **304** is a vertical well diode. In some embodiments, diode **304** is a nanosheet vertical well diode. In some embodiments, diode **304** is formed on a front side **305** of substrate **320**. Other diode types for diode **304** are within the scope of the present disclosure.

(81) Diode **304** corresponds to diode D2 of FIGS. 1-2, and similar detailed description is omitted. Anode **304a** corresponds to the anode of diode D2 of FIGS. 1-2, cathodes **304c** and **304d** corresponds to the cathode of diode D2 of FIGS. 1-2, and the channel region **304e** corresponds to a channel region of diode D2, and similar detailed description is omitted.

(82) Well **332** is formed in substrate **320**. Well **332** has n-type dopant impurities and is referred to as an N-type well. In some embodiments, well **332** has p-type dopant impurities and is referred to as a P-type well.

(83) Well **332** includes a region **334**. Region **334** is embedded in well **332**. Region **334** is a heavily doped n-region. In some embodiments, region **334** is a heavily doped p-region.

(84) The anode **304a** includes well **332** and region **334**. The anode **304a** is an N-type active region having N-type dopants in well **332**.

(85) The cathode **304c** is a P-type active region having P-type dopants and is located on well **332**. The cathode **304d** is a P-type active region having P-type dopants and is located on well **332**. In some embodiments, at least cathode **304c** or **304d** is an N-type active region having N-type dopants. The cathode **304c** and the cathode **304d** are separated from each other in the first direction X. In some embodiments, cathode **304c** and cathode **304d** are corresponding cathodes of two diodes coupled together in parallel. Integrated circuits **300A-300B** are shown with two cathodes (e.g., cathodes **304c** and **304d**) and a single anode (e.g., anode **304a**). Other number of cathodes **304c** or **304d** and/or anodes **304a** are within the scope of the present disclosure.

(86) The anode **304a** and the cathode **304c** together form a PN junction, and the anode **304a** and the cathode **304d** together form another PN junction. In some embodiments, at least cathode **304c** or cathode **304d** extends above substrate **320**. In some embodiments, at least a top surface of cathode **304c** or a top surface of cathode **304d** is flush with the front side **305** of substrate **320**.

(87) The gate structure **304b** is at least partially over well **332**, and in between cathode **304c** and cathode **304d**. In some embodiments, the gate structure **304b** is electrically floating. In some embodiments, the gate structure **304b** is electrically coupled to cathodes **304c** and **304d**. The channel region **304e** couples the cathode **304c** and the cathode **304d**. In some embodiments, the channel region **304e** is in well **332**.

(88) In some embodiments, diode **304** does not include a signal tap region. In some embodiments, diode **304** is configured to share a signal tap region **352** with ESD clamp circuit **310**. For example, in some embodiments, diode **304** is electrically coupled to the signal tap region **352** of ESD clamp circuit **310** by at least a conductive structure **392**. In some embodiments, by sharing signal tap region **352** with ESD clamp circuit **310**, integrated circuit **300A** or **300B** occupies less area than other approaches. In some embodiments, by sharing signal tap region **352** with ESD clamp circuit **310**, integrated circuit **300A** or **300B** has less signal taps than other approaches resulting in integrated circuit **300A** or **300B** having less resistance than other approaches, and simpler routing.

(89) Other types of circuits, configurations and arrangements diode **304** are within the scope of the present disclosure.

(90) ESD clamp circuit **310** includes an N-type Metal Oxide Semiconductor (NMOS) transistor **N1**, an NMOS transistor **N2**, signal tap region **250** and signal tap region **252**. NMOS transistor **N1** is coupled in series with NMOS transistor **N2**. For ease of illustration, NMOS transistor **N1** and NMOS transistor **N2** are not shown as being coupled to other elements in FIGS. **3A-3B**. In some embodiments, at least NMOS transistor **N1** or **N2** is a P-type Metal Oxide Semiconductor (PMOS) transistor.

(91) NMOS transistor **N1** includes a drain region **310a**, a gate structure **310b**, a source region **310c**, a channel region **310d** and a well region **360**.

(92) Well region **360** is formed in substrate **320**. Well region **360** has p-type dopant impurities and is referred to as a P-type well. In some embodiments, well region **360** has n-type dopant impurities and is referred to as an N-type well.

(93) The gate structure **310b** is over well region **360**. The drain region **310a** is an N-type active region having N-type dopants implanted in well region **360**. The source region **310c** is an N-type active region having N-type dopants implanted in well region **360**. In some embodiments, at least source region **310c** or drain region **310a** extends above substrate **320**. The channel region **310d** is in well region **360** and couples the drain region **310a** and the source region **310c**.

(94) NMOS transistor **N2** includes a drain region **312a**, a gate structure **312b**, a source region **312c**, a channel region **312d** and a well region **362**.

(95) Well region **362** is formed in substrate **320**. Well region **362** has p-type dopant impurities and is referred to as a P-type well. In some embodiments, well region **362** has n-type dopant impurities and is referred to as an N-type well.

(96) The gate structure **312b** is over well region **362**. The drain region **312a** is an N-type active region having N-type dopants implanted in well region **362**. The source region **312c** is an N-type active region having N-type dopants implanted in well region **362**. In some embodiments, at least source region **312c** or drain region **312a** extends above substrate **320**. The channel region **312d** is in well region **362** and couples the drain region **312a** and the source region **312c**.

(97) The signal tap region **350** is an embodiment of signal tap region **250** of FIG. **2**, and the signal tap region **352** is an embodiment of signal tap region **252** of FIG. **2**, and similar detailed description is therefore omitted.

(98) The signal tap region **350** is in well region **360**. Signal tap region **350** is coupled to a conductive structure **344**. Each of signal tap region **350** and conductive structure **344** are coupled to node **Nd1** which corresponds to the voltage supply terminal (e.g., voltage **VDD**). Signal tap region **350** is further coupled to cathode **302c** of diode **D1** and cathode **302d** of diode **D1** by a conductive line **390**. In some embodiments, the signal tap region **350** of ESD clamp circuit **310** is shared with diode **302**.

(99) In some embodiments, signal tap region **350** is a well tap, and electrically couples well region **360** of substrate **320** to voltage supply node **104** (e.g., supply voltage **VDD**). In some embodiments, the signal tap region **350** includes a heavily doped n-region in well region **360** on substrate **320** (e.g., P-type). In some embodiments, the heavily doped n-region is coupled through the well tap to voltage supply node **104** (e.g., supply voltage **VDD**) thereby setting the potential of the well region

360 (e.g., N-type) to prevent leakage from adjacent source/drain regions into well region **360**. In some embodiments, the signal tap region **350** includes a heavily doped p-region in well region **360** on substrate **320**.

(100) The signal tap region **352** is in well region **362**. In some embodiments, well region **362** and **360** are part of a same continuous well. In some embodiments, well region **362** and **360** are separate discontinuous wells. Signal tap region **352** is coupled to a conductive structure **346**.

(101) Each of signal tap region **352** and conductive structure **346** are coupled to node Nd2 which corresponds to the reference voltage supply terminal (e.g., voltage VSS). Signal tap region **352** is further coupled to cathode **304c** of diode D2 and cathode **304d** of diode D2 by a conductive line **392**. In some embodiments, signal tap region **352** of ESD clamp circuit **310** is shared with diode **304**.

(102) In some embodiments, signal tap region **352** is a substrate tap, and electrically couples well region **362** of substrate **320** to reference voltage supply node **106** (e.g., supply voltage VSS). In some embodiments, the signal tap region **352** includes a heavily doped p-region in well region **362** on substrate **320** (e.g., P-type). In some embodiments, the heavily doped p-region is coupled through the substrate tap to reference voltage supply node **106** (e.g., supply voltage VSS) thereby setting the potential of the substrate **320** (e.g., P-type) to prevent leakage from adjacent source/drain regions. In some embodiments, the signal tap region **352** includes a heavily doped n-region in well region **362** on substrate **320**.

(103) Each of the cathode **302c** of diode D1, the cathode **302d** of diode D1, and the signal tap region **350** are coupled together by conductive line **390** that corresponds to node Nd1 of FIGS. 1-2.

(104) Each of the cathode **304c** of diode D2, the cathode **304d** of diode D2, and the signal tap region **352** are coupled together by conductive line **392** that corresponds to node Nd2 of FIGS. 1-2.

(105) In some embodiments, the drain region **310a** and source region **310c** or the drain region **312a** and source region **312c** of ESD clamp circuit **310** of FIGS. 3A-3B is referred to as an oxide definition (OD) region which defines the source or drain diffusion regions of NMOS transistor N1 or N2 of FIGS. 3A-3B.

(106) In some embodiments, at least drain region **310a** or **312a** is an extended drain region and has a greater size than at least source region **310c** or **312c**. In at least one embodiment, a silicide layer (not shown) covers a portion, but not the entirety, of at least drain region **310a** or **312a**. Such a partially silicided configuration of drain region **310a** improves self-protection of NMOS transistor N1 or N2 of ESD clamp circuit **310** from ESD events. In at least one embodiment, at least drain region **310a** or **312a** is fully silicided.

(107) Gate structure **310b** is arranged between drain region **310a** and source region **310c**. Gate structure **312b** is arranged between drain region **312a** and source region **312c**. In some embodiments, the gate structure **310b** and gate structure **312b** are electrically coupled together.

(108) In some embodiments, at least gate structure **302b**, **304b**, **310b** or **312b** is a metal gate, and includes a conductive material such as a metal. In some embodiments, at least gate structure **302b**, **304b**, **310b** or **312b** includes polysilicon (also referred to herein as "POLY").

(109) In some embodiments, at least channel region **302e**, **304e**, **310d** or **312d** includes fins in accordance with fin field-effect transistor (FinFET) complementary metal-oxide-semiconductor (CMOS) technologies. In some embodiments, at least channel region **302e**, **304e**, **310d** or **312d** includes nanosheets of nanosheet transistors. In some embodiments, at least channel region **302e**, **304e**, **310d** or **312d** includes nanowire of nanowire transistors. In some embodiments, at least channel region **302e**, **304e**, **310d** or **312d** is free of fins in accordance with planar CMOS technologies. Other types of transistors are within the scope of the present disclosure.

(110) Other types of circuits, configurations and arrangements of ESD clamp circuit **310** are within the scope of the present disclosure.

(111) Integrated circuit **300A** further includes one or more shallow trench isolation (STI) regions **328a**, **328b**, **328c** or **328d**.

(112) STI region **328a** is adjacent to anode **304a** of diode **304**. STI region **328b** is between diode **302** and ESD clamp circuit **310**. STI region **328c** is between diode **304** and ESD clamp circuit **310**. STI region **328d** is adjacent to cathode **302d** of diode **302**.

(113) STI region **328a** is configured to electrically isolate portions of diode **304** from other portions of integrated circuit **300A** or **300B** (not shown). STI region **328b** is configured to electrically isolate portions of diode **304** and portions of ESD clamp circuit **310** from each other. In some embodiments, STI region **328c** is configured to electrically isolate at least portions of diode **302** and portions of ESD clamp circuit **310** from each other. STI region **328d** is configured to electrically isolate portions of diode **302** from other portions of integrated circuit **300A** or **300B** (not shown).

(114) In some embodiments, at least STI region **328a**, **328b**, **328c** or **328d** is not included in integrated circuit **300A** or **300B**. In some embodiments, in at least integrated circuit **300A** or **300B**, at least STI region **328a**, **328b**, **328c** or **328d** is replaced with a corresponding dummy cell. In some embodiments, the dummy cell is a dummy device. In some embodiments, a dummy device is a non-functional transistor or non-functional diode device.

(115) In some embodiments, well region **322** and well region **360** are part of a same continuous well. In some embodiments, well region **322** and **360** are separate discontinuous wells, and STI region **328** is positioned between them.

(116) In some embodiments, well region **332** and well region **362** are part of a same continuous well. In some embodiments, well region **322** and **362** are separate discontinuous wells, and STI region **338** is positioned between them.

(117) In some embodiments, well region **360** is positioned between well region **362** and well region **322**. In some embodiments, well region **360** is adjacent to at least well region **362** or well region **322**. In some embodiments, a first element is adjacent to a second element corresponds to the first element being directly next to the second element. In some embodiments, the first element is adjacent to the second element corresponds to the first element not being directly next to the second element. In some embodiments, diode **302** is adjacent to ESD clamp circuit **310**. In some embodiments, signal tap region **350** is adjacent to cathode **302c**.

(118) In some embodiments, well region **362** is positioned between well region **360** and well region **332**. In some embodiments, well region **362** is adjacent to at least well region **360** or well region **332**. In some embodiments, diode **304** is adjacent to ESD clamp circuit **310**. In some embodiments, signal tap region **352** is adjacent to cathode **304c**.

(119) Other types of circuits, configurations and arrangements of ESD clamp circuit **310** are within the scope of the present disclosure.

(120) Integrated circuit **300A** further includes a conductive structure **340**, a conductive structure **342**, a conductive structure **344** and a conductive structure **346**. Conductive structure **340**, conductive structure **342**, conductive structure **344** and conductive structure **346** are formed on the backside **203** of integrated circuits **300A-300B**. In some embodiments, at least conductive structure **340**, conductive structure **342**, conductive structure **344** or conductive structure **346** is embedded in substrate **320**. In some embodiments, at least conductive structure **340**, conductive structure **342**, conductive structure **344** or conductive structure **346** is configured to provide an electrical connection between one or more circuit elements of integrated circuit **300A-300B** and other one or more circuit elements of integrated circuit **300A-300B** or other package structures (not shown).

(121) In some embodiments, each of conductive structure **340**, conductive structure **342** and conductive structure **344** and conductive structure **346** is a corresponding via. In some embodiments, one or more of conductive structure **340**, conductive structure **342** and conductive structure **344**, conductive structure **346** or signal tap **350** are used to electrically couple signals from the front-side **305** to the back-side **303** of substrate **320** since the front-side **305** and the back-side **303** are electrically isolated from each other by at least the insulating layer **321**. In some embodiments, at least conductive structure **340**, **342**, **344** or **346** is directly coupled with

corresponding source/drain region **310a**, **310c** or **312c**.

(122) In some embodiments, integrated circuit **300A** is electrically connected to one or more other package structures (not shown) on the backside **203** of substrate **320** by at least conductive structure **340**, conductive structure **342**, conductive structure **344** or conductive structure **346**.

(123) In some embodiments, at least conductive structure **340**, conductive structure **342**, conductive structure **344** or conductive structure **346** corresponds to a copper pillar structure that includes at least a conductive material such as copper, or the like.

(124) In some embodiments, at least conductive structure **340**, conductive structure **342**, conductive structure **344** or conductive structure **346** corresponds to a solder bump structure that includes a conductive material having a low resistivity, such as solder or a solder alloy. In some embodiments, a solder alloy includes Sn, Pb, Ag, Cu, Ni, Bi, or combinations thereof. Other configurations, arrangements and materials of at least conductive structure **340**, conductive structure **342**, conductive structure **344** or conductive structure **346** are within the contemplated scope of the present disclosure.

(125) Conductive structure **340** is coupled to the anode region **302a** of diode **302**. Conductive structure **340** is coupled to the well region **322** and region **324** of diode **302**. In some embodiments, conductive structure **340** corresponds to node Nd3 of FIGS. 1-2. In some embodiments, conductive structure **340** is electrically coupled to node Nd3 of FIGS. 1-2. In some embodiments, conductive structure **340** is electrically coupled to IO pad **108** of FIGS. 1-2.

(126) Conductive structure **342** is coupled to the anode region **304a** of diode **304**. Conductive structure **342** is coupled to the well region **332** and region **334** of diode **304**. In some embodiments, conductive structure **342** corresponds to node Nd3 of FIGS. 1-2. In some embodiments, conductive structure **342** is electrically coupled to node Nd3 of FIGS. 1-2. In some embodiments, conductive structure **342** is electrically coupled to IO pad **108** of FIGS. 1-2.

(127) In some embodiments, conductive structure **340** and conductive structure **342** are coupled to each other. For ease of illustration, conductive structure **340** and conductive structure **342** are not shown as being coupled to each other.

(128) Conductive structure **344** is coupled to signal tap region **350**. Conductive structure **344** is configured to provide voltage VDD to signal tap region **350**. In some embodiments, conductive structure **344** is electrically coupled to voltage supply node **104** (e.g., voltage VDD) of FIGS. 1-2. In some embodiments, conductive structure **344** corresponds to node Nd1 of FIGS. 1-2. In some embodiments, conductive structure **344** corresponds to a pad or a pin. In some embodiments, conductive structure **344** is electrically coupled to node Nd1 of FIGS. 1-2. In some embodiments, conductive structure **344** corresponds to node Nd1 of FIGS. 1-2.

(129) Conductive structure **346** is coupled to signal tap region **352**. Conductive structure **346** is configured to provide voltage VSS to signal tap region **352**. In some embodiments, conductive structure **346** is electrically coupled to reference voltage supply node **106** (e.g., voltage VSS) of FIGS. 1-2. In some embodiments, conductive structure **346** corresponds to node Nd2 of FIGS. 1-2. In some embodiments, conductive structure **346** corresponds to a pad or a pin. In some embodiments, conductive structure **346** is electrically coupled to node Nd2 of FIGS. 1-2. In some embodiments, conductive structure **346** corresponds to node Nd2 of FIGS. 1-2.

(130) In some embodiments, at least conductive structure **340**, **342**, **344**, **346**, **390** or **392** includes one or more layers of a conductive material. In some embodiments, the conductive material includes Tungsten, Cobalt, Ruthenium, Copper, or the like or combinations thereof.

(131) Other configurations, arrangements and materials of at least conductive structure **340**, **342**, **344**, **346**, **390** or **392** are within the contemplated scope of the present disclosure.

(132) Other configurations or quantities of circuits in integrated circuit **300A** are within the scope of the present disclosure.

(133) During a PD mode of ESD stress or event, diode **302** is forward biased and current I2 flows through diode **302** from the anode **302a** to the cathode **302c** and cathode **302d**. Diode **302** is

configured to transfer current I2 or ESD voltage from IO pad 108 (node Nd3) to node Nd1. Current I2 flows directly from cathode 302c and cathode 302d to signal tap region 350 of ESD clamp circuit 302. In response to current I2 and ESD voltage at node Nd1, NMOS transistors N1 and N2 in ESD clamp circuit 310 are configured to turn on, and discharge the ESD current I2 from signal tap region 350 or node Nd1 through channel regions 310d and 312d to the reference voltage supply node 106 (e.g., VSS) by signal tap region 352 and node Nd2.

(134) In some embodiments, by sharing signal tap region 350 with ESD clamp circuit 310, integrated circuit 300A has less signal taps than other approaches, resulting in current I2 flowing through less signal taps than other approaches, and to flow directly from cathode 302c and cathode 302d to signal tap region 350 of ESD clamp circuit 320 thereby reducing the signal tap resistance of integrated circuit 300A compared to other approaches.

(135) FIG. 3B is a cross-sectional view of an integrated circuit 300B, in accordance with some embodiments.

(136) Integrated circuit 300B is an embodiment of at least ESD clamp circuit 120 or 310, and similar detailed description is therefore omitted. Integrated circuit 300B is an embodiment of integrated circuit 300B, and similar detailed description is therefore omitted.

(137) Integrated circuit 300B is an embodiment of at least integrated circuit 100 of FIG. 1 or integrated circuit 200 of FIG. 2, and similar detailed description is therefore omitted.

(138) Integrated circuit 300B is a variation of integrated circuit 300A of FIG. 3A, and similar detailed description is therefore omitted. In comparison with integrated circuit 300A, current I1 replaces current I2, and similar detailed description is therefore omitted. In other words, integrated circuit 300B is configured to show ESD current flow during a PS mode of ESD stress.

(139) During a PS mode of ESD stress or event, diode 304 is reverse biased and current I1 flows through diode 304 from the anode 304a to the cathode 304c and cathode 304d. Diode 304 is configured to transfer current I1 or ESD voltage from IO pad 108 (node Nd3) to node Nd2. Current I1 flows directly from cathode 304c and cathode 304d to signal tap region 352 of ESD clamp circuit 302. In response to current I1 and ESD voltage at node Nd2, NMOS transistors N2 and N1 in ESD clamp circuit 310 are configured to turn on, and discharge the ESD current I1 from signal tap region 352 or node Nd2 through channel regions 312d and 310d to the voltage supply node 104 (e.g., VDD) by signal tap region 350 and node Nd1.

(140) In some embodiments, by sharing signal tap region 352 with ESD clamp circuit 310, integrated circuit 300B has less signal taps than other approaches, resulting in current I1 flowing through less signal taps than other approaches, and to flow directly from cathode 304c and cathode 304d to signal tap region 352 of ESD clamp circuit 320 thereby reducing the signal tap resistance of integrated circuit 300B compared to other approaches.

(141) Other configurations or quantities of circuits in integrated circuit 300B are within the scope of the present disclosure.

(142) FIG. 4 is a circuit diagram of an integrated circuit 400, in accordance with some embodiments.

(143) Integrated circuit 400 is an embodiment of at least ESD clamp circuit 120 of FIG. 1, and similar detailed description is therefore omitted. In some embodiments, integrated circuit 400 is an equivalent circuit for ESD clamp circuit 310 of FIGS. 3A-3B. In some embodiments, NMOS transistor N1 of FIG. 4 corresponds to NMOS transistor N1 of FIGS. 3A-3B, and NMOS transistor N2 of FIG. 4 corresponds to NMOS transistor N2 of FIGS. 3A-3B.

(144) Integrated circuit 400 includes a resistor R1, a capacitor C1, an inverter I1, an NMOS transistor N1 and an NMOS transistor N2. In some embodiments, NMOS transistor N1 and NMOS transistor N2 are referred to as an ESD discharging circuit that is configured to couple node Nd1 and Nd2 during an ESD event at node Nd1 or node Nd2, thereby providing an ESD discharge path between node Nd1 and Nd2.

(145) Each of a first end of resistor R1, node Nd1, a first voltage supply node (not labelled) of

inverter I1 and a drain of NMOS transistor N1 are coupled together. Each of a second end of resistor R1, a first end of capacitor C1, an input terminal of inverter I1 and a node Nd4 are coupled together.

(146) Each of a second end of capacitor C1, node Nd2, a source of NMOS transistor N2, a body of NMOS transistor N1, a body of NMOS transistor N2 and a second voltage supply node (not labelled) of inverter I1 are coupled together.

(147) An output terminal of inverter I1 is coupled to a gate of NMOS transistor N1 and a gate of NMOS transistor N2.

(148) In some embodiments, capacitor C1 is a transistor-coupled capacitor. For example in some embodiments, capacitor C1 is a transistor having a drain and source coupled together thereby forming a transistor-coupled capacitor.

(149) Resistor R1 and capacitor C1 are configured as an RC network. Dependent upon a location of an output of the RC network, the RC network is configured as either a low pass filter or a high pass filter.

(150) In some embodiments, inverter I1 includes an NMOS transistor (not shown) and a PMOS transistor (not shown) coupled together as an inverter circuit. Thus, a slowly rising voltage at node Nd4 will be inverted by inverter I1 thereby causing node Nd3 to rapidly rise. Furthermore, a rapidly rising voltage at node Nd4 will be inverted by inverter I1 thereby causing node Nd3 to rise slowly. In some embodiments, inverter I1 is configured to generate an inverted input signal (not shown) in response to an input signal (not shown).

(151) When an ESD event at node Nd1 occurs (e.g., ESD current I2a in the reverse ESD direction), the ESD current or voltage at node Nd1 rises rapidly causing the voltage of node Nd4 (e.g., across capacitor C1) to rise slowly (e.g., slower than rapidly) since the voltage at node Nd4 corresponds to an output voltage of a low pass filter (e.g., a voltage across capacitor C1 with respect to node Nd2). In other words, capacitor C1 is configured as a low pass filter, and the rapidly changing voltage or current from the ESD event is filtered by capacitor C1. In response to the slowly rising voltage at node Nd4, a PMOS transistor (not shown) in inverter I1 will turn on thereby coupling node Nd3 to node Nd1 and causing node Nd3 to rapidly rise from the ESD event at node Nd1. Thus, node Nd3 and the gate of NMOS transistors N1 and N2 are charged by the ESD event at node Nd1. In response to being charged by the ESD event at node Nd3, NMOS transistors N1 and N2 turn on and couple node Nd1 to node Nd2. By being turned on and coupling node Nd1 to node Nd2, the channels of NMOS transistors N1 and N2 discharge the ESD current I2a in the reverse ESD direction from node Nd1 to Nd2.

(152) When an ESD event at node Nd2 occurs (e.g., ESD current I1a flows in the forward ESD direction), the ESD current or voltage at node Nd2 rises rapidly, causing the voltage of node Nd4 (e.g., across capacitor C1) to rise as well. However, a rising voltage at node Nd4 will be inverted by inverter I1 thereby causing node Nd3 to not rise from the ESD event at node Nd2 causing NMOS transistors N1 and N2 to not turn on, and NMOS transistors N1 and N2 have a minimal effect on an ESD event at node Nd2.

(153) Other configurations or quantities of circuits in integrated circuit 400 are within the scope of the present disclosure.

(154) FIG. 5 is a flowchart of a method 500 of operating an ESD circuit, in accordance with some embodiments. In some embodiments, the circuit of method 500 includes at least integrated circuit 100, 200 or 300A-300B (FIG. 1, 2 or 3A-3B). It is understood that additional operations may be performed before, during, and/or after the method 500 depicted in FIG. 5, and that some other processes may only be briefly described herein. It is understood that method 500 utilizes features of one or more of integrated circuit 100, 200 or 300A-300B.

(155) Method 500 is applicable to at least integrated circuit 300A or 300B. Method 500 is initially described with respect to integrated circuit 300A and current path I2. However, method 500 is also applicable to integrated circuit 300B and current path I1, and is described below after the

description of integrated circuit **300A**. Other order of operations of method **500** to integrated circuit **300A** or **300B** is within the scope of the present disclosure.

(156) At operation **502** of method **500**, an ESD voltage of an ESD event is received on a first node. In some embodiments, the ESD voltage is greater than a supply voltage VDD of a voltage supply. In some embodiments, the first node of method **500** includes node Nd3. In some embodiments, the first node of method **500** includes at least IO pad **108**, conductive structure **340** or conductive structure **342**.

(157) At operation **504**, a diode is turned on, thereby conducting an ESD current from an anode of the diode to a cathode of the diode. In some embodiments, the diode of method **500** includes at least diode D1 or **302**. In some embodiments, the anode of method **500** includes at least the anode of diode D1 or anode **302a**. In some embodiments, the cathode of method **500** includes at least the cathode of diode D1, cathode **302c** or **302d**. In some embodiments, the ESD current of method **500** includes current I2.

(158) At operation **506**, the ESD current is conducted from the cathode of the diode to a first signal tap of a clamp circuit. In some embodiments, the first signal tap of method **500** includes at least signal tap **250** or **350**. In some embodiments, the clamp circuit of method **500** includes at least ESD clamp circuit **120**, **220**, or **310**.

(159) At operation **508**, the ESD current of the ESD event is discharged by the ESD clamp circuit. In some embodiments, the ESD current of the ESD event is discharged by a channel of a first transistor or a channel of a second transistor. In some embodiments, the first transistor of method **500** includes NMOS transistor N1, and the channel includes channel region **310d**. In some embodiments, the second transistor of method **500** includes NMOS transistor N2, and the channel includes channel region **312d**.

(160) In some embodiments, operation **508** includes at least operation **510**, **512**, **514** or **516**.

(161) At operation **510**, the ESD clamp circuit is turned on in response to the ESD current being received at the first signal tap of the ESD clamp circuit or a second node. In some embodiments, the second node of method **500** includes node Nd1. In some embodiments, the second node of method **500** corresponds to conductive structure **390**.

(162) At operation **512**, the second node is coupled to a third node in response to the ESD clamp circuit turning on. In some embodiments, the third node of method **500** includes node Nd2. In some embodiments, the third node of method **500** corresponds to conductive structure **392**. In some embodiments, the second node is coupled to the third node in response to the NMOS transistor N1 and NMOS transistor N2 of ESD clamp circuit turning on.

(163) At operation **514**, the ESD current is conducted from the first signal tap or the second node to a second signal tap of the ESD clamp circuit. In some embodiments, the second signal tap of method **500** includes at least signal tap **252** or **352**.

(164) At operation **516**, the ESD current is conducted from the second signal tap of the clamp circuit to a fourth node. In some embodiments, the fourth node of method **500** includes at least reference voltage supply node **106** (e.g., voltage VSS) or conductive structure **346**.

(165) While method **500** was described with respect to integrated circuit **300A** and current path I2, method **500** is also applicable to integrated circuit **300B** and current path I1 and is described below with similar operations.

(166) For example, at operation **502**, the ESD voltage of the ESD event is received on the first node. In some embodiments, the ESD voltage is greater than a reference supply voltage VSS of reference voltage supply node **106**. In some embodiments, the first node of method **500** includes at least IO pad **108** or conductive structure **342**.

(167) At operation **504**, the diode is turned on, thereby conducting the ESD current from the anode of the diode to the cathode of the diode. In some embodiments, the diode of method **500** includes at least diode D2 or **304**. In some embodiments, the anode of method **500** includes at least the anode of diode D2 or anode **304a**. In some embodiments, the cathode of method **500** includes at least the

cathode of diode D2, cathode 304c or 304d. In some embodiments, the ESD current of method 500 includes current I1.

(168) At operation 506, the ESD current is conducted from the cathode of the diode to the first signal tap of the clamp circuit. In some embodiments, the first signal tap of method 500 includes at least signal tap 252 or 352.

(169) At operation 508, the ESD current of the ESD event is discharged by the ESD clamp circuit. In some embodiments, the SD current of the ESD event is discharged by channel region 312d of NMOS transistor N2 and channel region 310d of NMOS transistor N1.

(170) At operation 510, the ESD clamp circuit is turned on in response to the ESD current being received at the first signal tap of the ESD clamp circuit or the second node. In some embodiments, the second node of method 500 includes node Nd2. In some embodiments, the second node of method 500 corresponds to conductive structure 392.

(171) At operation 512, the second node is coupled to the third node in response to the ESD clamp circuit turning on. In some embodiments, the third node of method 500 includes node Nd1. In some embodiments, the third node of method 500 corresponds to conductive structure 390. In some embodiments, the second node is coupled to the third node in response to the NMOS transistor N1 and NMOS transistor N2 of ESD clamp circuit turning on.

(172) At operation 514, the ESD current is conducted from the first signal tap or the second node to the second signal tap of the ESD clamp circuit. In some embodiments, the second signal tap of method 500 includes at least signal tap 250 or 350.

(173) At operation 516, the ESD current is conducted from the second signal tap of the clamp circuit to the fourth node. In some embodiments, the fourth node of method 500 includes at least voltage supply node 104 (e.g., voltage VDD) or conductive structure 344.

(174) In some embodiments, one or more of the operations of method 500 is not performed. In some embodiments, one or more of the operations of method 500 is repeated. In some embodiments, method 500 is repeated.

(175) FIG. 6 is a flow chart of a method of manufacturing an integrated circuit, in accordance with some embodiments. In some embodiments, the method 600 is usable to manufacture or fabricate at least integrated circuit 100, 200 or 300A-300B (FIG. 1, 2 or 3A-3B). It is understood that additional operations may be performed before, during, and/or after the method 600 depicted in FIG. 6, and that some other processes may only be briefly described herein. It is understood that method 600 utilizes features of one or more of integrated circuit 100, 200 or 300A-300B.

(176) Method 600 is applicable to at least integrated circuit 300A or 300B. Method 600 is described with respect to integrated circuit 300A. However, method 600 is also applicable to integrated circuit 300B. Other order of operations of method 600 to integrated circuit 300A or 300B is within the scope of the present disclosure.

(177) In operation 602 of method 600, a first diode is fabricated on a front-side of a wafer. In some embodiments, the wafer of method 600 includes substrate 320. In some embodiments, the front-side of the wafer of method 600 includes at least front-side 305 of substrate 320. In some embodiments, the first diode of method 600 includes at least diode 302.

(178) In some embodiments, operation 602 includes at least operation 602a or 602b. In some embodiments, operation 602a includes depositing an oxide layer 704 (FIGS. 7A-7E) on the front-side 305 of substrate 320 and is shown in FIG. 7A.

(179) In some embodiments, operation 602b includes forming an opening in the oxide layer 704, and then filling the opening in the oxide layer with a conductive material thereby forming a via 706 (FIG. 7B), and growing an epitaxial layer 708 (FIG. 7B) in an unfilled portion of the opening and is shown in FIG. 7B. In some embodiments, the epitaxial layer 708 (FIG. 7B) corresponds to cathode region 302c and 302d.

(180) In some embodiments, operation 602 further includes fabricating well 322 in substrate 320, fabricating a heavily doped region 324 in well 322 thereby forming anode region 302a of the first

diode, fabricating cathode region **302c** and **302d** in well **322**, and fabricating gate structure **302b**. (181) In some embodiments, at least well **322**, well **360** or **362** (e.g., ESD clamp circuit **310**) comprises p-type dopants. In some embodiments, the p-dopants include boron, aluminum or other suitable p-type dopants. In some embodiments, at least well **322**, well **360** or **362** comprises an epi-layer grown over substrate **320**. In some embodiments, the epi-layer is doped by adding dopants during the epitaxial process. In some embodiments, the epi-layer is doped by ion implantation after the epi-layer is formed. In some embodiments, at least well **322**, well **360** or **362** is formed by doping substrate **320**. In some embodiments, the doping is performed by ion implantation. In some embodiments, at least well **322**, well **360** or **362** has a dopant concentration ranging from 1×10^{12} atoms/cm³ to 1×10^{14} atoms/cm³. In some embodiments, region **324** is formed by a process similar to the formation of well **322**. In some embodiments, region **324** is a heavily doped p-region.

(182) In some embodiments, at least fabricating cathode regions **302c** and **302d** of operation **602** or fabricating cathode regions **304c** and **304d** of operation **604** (described below) includes the formation of cathode features in the substrate. In some embodiments, the formation of the cathode features includes removing a portion of the substrate to form recesses at an edge of well **322** or **332**, and a filling process is then performed by filling the recesses in the substrate. In some embodiments, the recesses are etched, for example, by a wet etching or a dry etching, after removal of a pad oxide layer or a sacrificial oxide layer. In some embodiments, the etch process is performed to remove a top surface portion of the active region adjacent to an isolation region, such as STI region **328a**, **328b**, **328c** or **328d**. In some embodiments, the filling process is performed by an epitaxy or epitaxial (epi) process. In some embodiments, the recesses are filled using a growth process which is concurrent with an etch process where a growth rate of the growth process is greater than an etch rate of the etch process. In some embodiments, the recesses are filled using a combination of growth process and etch process. For example, a layer of material is grown in the recess and then the grown material is subjected to an etch process to remove a portion of the material. Then a subsequent growth process is performed on the etched material until a desired thickness of the material in the recess is achieved. In some embodiments, the growth process continues until a top surface of the material is above the top surface of the substrate. In some embodiments, the growth process is continued until the top surface of the material is co-planar with the top surface of the substrate. In some embodiments, a portion of well **322** or **332** is removed by an isotropic or an anisotropic etch process. The etch process selectively etches well **322** or **332** without etching gate structure **302b** or **304b**. In some embodiments, the etch process is performed using a reactive ion etch (RIE), wet etching, or other suitable techniques. In some embodiments, a semiconductor material is deposited in the recesses to form the cathode features similar to source/drain features. In some embodiments, an epi process is performed to deposit the semiconductor material in the recesses. In some embodiments, the epi process includes a selective epitaxy growth (SEG) process, CVD process, molecular beam epitaxy (MBE), other suitable processes, and/or combination thereof. The epi process uses gaseous and/or liquid precursors, which interacts with a composition of substrate **320**. In some embodiments, the cathode features include epitaxially grown silicon (epi Si), silicon carbide, or silicon germanium. Cathode features of the IC device associated with gate structure **302b** or **304b** are in-situ doped or undoped during the epi process in some instances. When cathode features are undoped during the epi process, cathode features are doped during a subsequent process in some instances. The subsequent doping process is achieved by an ion implantation, plasma immersion ion implantation, gas and/or solid source diffusion, other suitable processes, and/or combination thereof. In some embodiments, cathode features are further exposed to annealing processes after forming cathode features and/or after the subsequent doping process.

(183) In some embodiments, at least fabricating the gate regions of operation **602**, **604** or **606** (described below) includes performing one or more deposition processes to form one or more

dielectric material layers. In some embodiments, a deposition process includes a chemical vapor deposition (CVD), a plasma enhanced CVD (PECVD), an atomic layer deposition (ALD), or other process suitable for depositing one or more material layers. In some embodiments, fabricating the gate regions includes performing one or more deposition processes to form one or more conductive material layers. In some embodiments, fabricating the gate regions includes forming gate electrodes or dummy gate electrodes. In some embodiments, fabricating the gate regions includes depositing or growing at least one dielectric layer, e.g., gate dielectric. In some embodiments, gate regions are formed using a doped or non-doped polycrystalline silicon (or polysilicon). In some embodiments, the gate regions include a metal, such as Al, Cu, W, Ti, Ta, TiN, TaN, NiSi, CoSi, other suitable conductive materials, or combinations thereof.

(184) In operation **604** of method **600**, a second diode is fabricated on the front-side of the wafer. In some embodiments, the back-side of the wafer of method **600** includes at least back-side **303** of substrate **320**. In some embodiments, the second diode of method **600** includes at least diode **304**.

(185) In some embodiments, operation **604** includes at least operation **604a** or **604b**. In some embodiments, operation **604a** includes depositing oxide layer **704** (FIGS. 7A-7E) on the front-side **305** of substrate **320** and is shown in FIG. 7A.

(186) In some embodiments, operation **604b** includes forming an opening in the oxide layer **704**, and then filling the opening in the oxide layer with a conductive material thereby forming a via **706** (FIG. 7B), and growing an epitaxial layer **708** (FIG. 7B) is grown in an unfilled portion of the opening and is shown in FIG. 7B. In some embodiments, the epitaxial layer **708** (FIG. 7B) corresponds to cathode region **304c** and **304d**.

(187) In some embodiments, operation **604** further includes fabricating well **332** in substrate **320**, fabricating a heavily doped region **334** in well **332** thereby forming anode region **304a** of the second diode, fabricating cathode region **304c** and **304d** above well **332**, and fabricating gate structure **304b**.

(188) In some embodiments, well **332** comprises n-type dopants. In some embodiments, the n-type dopants include phosphorus, arsenic or other suitable n-type dopants. In some embodiments, the n-type dopant concentration ranges from about 1×10^{12} atoms/cm³ to about 1×10^{14} atoms/cm³. In some embodiments, well **332** is formed by ion implantation. The power of the ion implantation ranges from about 1500 k electron volts (eV) to about 8000 k eV. In some embodiments, well **332** is epitaxially grown. In some embodiments, well **332** comprises an epi-layer grown over the surface. In some embodiments, the epi-layer is doped by adding dopants during the epitaxial process. In some embodiments, the epi-layer is doped by ion implantation after the epi-layer is formed, and has the dopant concentration described above. In some embodiments, region **334** is formed by a process similar to the formation of well **332**. In some embodiments, region **334** is a heavily doped n-region.

(189) In operation **606** of method **600**, an ESD clamp circuit is fabricated on the front-side of the wafer. In some embodiments, the ESD clamp circuit of method **600** includes at least ESD clamp circuit **310**.

(190) In some embodiments, operation **606** includes at least operation **606a** or **606b**. In some embodiments, operation **606a** includes depositing oxide layer **704** (FIGS. 7A-7E) on the front-side **305** of substrate **320** and is shown in FIG. 7A.

(191) In some embodiments, operation **606b** includes forming an opening in the oxide layer **704**, and then filling the opening in the oxide layer with a conductive material thereby forming a via **706** (FIG. 7B), and growing an epitaxial layer **708** (FIG. 7B) in an unfilled portion of the opening and is shown in FIG. 7B. In some embodiments, the epitaxial layer **708** (FIG. 7B) corresponds to source **310c** or **312c** and drain **310a** or **312a**.

(192) In some embodiments, operation **606** further includes fabricating wells **360** and **362** in substrate **320**, fabricating source/drain regions (e.g., source **310c** and drain **310a**) in well **360**, and fabricating source/drain regions (e.g., source **312c** and drain **312a**) in well **362**, and fabricating gate

structures **310b** and **312b**.

(193) In some embodiments, fabricating source/drain regions (e.g., source **310c** and drain **310a**) in well **360** of operation **606** includes operation **608**. In some embodiments, fabricating source/drain regions (e.g., source **312c** and drain **312a**) in well **362** of operation **606**, and fabricating gate structures **310b** and **312b** includes operation **610**.

(194) In operation **608** of method **600**, a first signal tap region is fabricated on the front-side of the wafer. In some embodiments, the first signal tap region of method **600** includes at least signal tap region **350**. In some embodiments, signal tap region **350** corresponds to drain **310a** of ESD clamp circuit **310**. In some embodiments, operation **608** corresponds to operation **606b**.

(195) In operation **610** of method **600**, a second signal tap is fabricated on the front-side of the wafer. In some embodiments, the second signal tap region of method **600** includes at least signal tap region **352**. In some embodiments, signal tap region **352** corresponds to source **312c** of ESD clamp circuit **310**. In some embodiments, operation **608** corresponds to operation **606b**.

(196) In some embodiments, at least signal tap region **350** or **352** comprises p-type dopants. In some embodiments, the p-dopants include boron, aluminum or other suitable p-type dopants. In some embodiments, at least signal tap region **350** or **352** is formed by a process similar to the formation of corresponding well **360** or **362**. In some embodiments, at least signal tap region **350** or **352** is a heavily doped p-region.

(197) In some embodiments, at least signal tap region **350** or **352** comprises n-type dopants. In some embodiments, the n-type dopants include phosphorus, arsenic or other suitable n-type dopants. In some embodiments, the n-type dopant concentration ranges from about 1×10^{12} atoms/cm² to about 1×10^{14} atoms/cm². In some embodiments, at least signal tap region **350** or **352** is formed by ion implantation. The power of the ion implantation ranges from about 1500 k electron volts (eV) to about 8000 k eV. In some embodiments, at least signal tap region **350** or **352** is a heavily doped n-region.

(198) In some embodiments, at least signal tap region **350** or **352** is epitaxially grown. In some embodiments, at least signal tap region **350** or **352** comprises an epi-layer grown over substrate **320**. In some embodiments, the epi-layer is doped by adding dopants during the epitaxial process. In some embodiments, the epi-layer is doped by ion implantation after the epi-layer is formed. In some embodiments, at least signal tap region **350** or **352** is formed by doping substrate **320**. In some embodiments, the doping is performed by ion implantation. In some embodiments, at least signal tap region **350** or **352** has a dopant concentration ranging from 1×10^{12} atoms/cm³ to 1×10^{14} atoms/cm³.

(199) In operation **612** of method **600**, a first set of conductive structures **710** (FIG. 7C) is fabricated on the front-side **305** of the wafer **320**. FIG. 7C is a cross-sectional view of the first set of conductive structures **710** fabricated on the front-side **305** of the wafer **320** following at least operation **612**, in accordance with one or more embodiments.

(200) In some embodiments, operation **612** includes depositing the first set of conductive structures **710** on the front-side **305** of the wafer **320**. In some embodiments, the first set of conductive structures **710** of method **600** includes at least conductive structure **390** and conductive structure **392**.

(201) In some embodiments, operation **612** includes depositing an insulating layer **712** (FIG. 7C) on the front-side **305** of the wafer **320**, removing portions of the insulating layer **712** from the front-side **305** of the wafer **320**, and depositing the first set of conductive structures **710** in the removed portions of the insulating layer **712** on the front-side **305** of the wafer **320**. In some embodiments, the first set of conductive structures of method **600** are formed using a combination of photolithography and material removal processes to form openings in an insulating layer (not shown) over the substrate. In some embodiments, the photolithography process includes patterning a photoresist, such as a positive photoresist or a negative photoresist. In some embodiments, the photolithography process includes forming a hard mask, an antireflective structure, or another

suitable photolithography structure. In some embodiments, the material removal process includes a wet etching process, a dry etching process, an RIE process, laser drilling or another suitable etching process. The openings are then filled with conductive material, e.g., copper, aluminum, titanium, nickel, tungsten, or other suitable conductive material. In some embodiments, the openings are filled using CVD, PVD, sputtering, ALD or other suitable formation process.

(202) In operation **614** of method **600**, wafer thinning is performed on the back-side **303** of the wafer. FIG. 7D is a cross-sectional view of the wafer **320** prior to the wafer thinning of operation **614**, in accordance with one or more embodiments.

(203) In some embodiments, operation **614** includes flipping the wafer **320** over, and performing a thinning process on the back-side **303** of the semiconductor wafer or substrate. In some embodiments, the thinning process includes a grinding operation and a polishing operation (such as chemical mechanical polishing (CMP)) or other suitable processes. In some embodiments, after the thinning process, a wet etching operation is performed to remove defects formed on the backside **303** of the semiconductor wafer **320** or substrate.

(204) In operation **616** of method **600**, an insulating layer **722** (FIG. 7E) is deposited on the back-side of the wafer. In some embodiments, the insulating layer **722** of method **600** includes insulating layer **321**. In some embodiments, the insulating layer **321** includes a dielectric material including oxide or another suitable insulating material. In some embodiments, the insulating layer **321** is formed by CVD, spin-on polymeric dielectric, atomic layer deposition (ALD), or other processes.

(205) In operation **618** of method **600**, portions of the insulating layer **722** are removed from the back-side of the wafer. In some embodiments, operation **618** of method **600** uses a combination of photolithography and material removal processes to form openings in an insulating layer **722** over the wafer **320**. In some embodiments, the photolithography process includes patterning a photoresist, such as a positive photoresist or a negative photoresist. In some embodiments, the photolithography process includes forming a hard mask, an antireflective structure, or another suitable photolithography structure. In some embodiments, the material removal process includes a wet etching process, a dry etching process, an RIE process, laser drilling or another suitable etching process.

(206) In operation **620** of method **600**, a second set of conductive structures **720** (FIG. 7E) is deposited in at least the removed portion of the insulating layer. FIG. 7E is a cross-sectional view of the wafer **320** following at least operation **620**, in accordance with one or more embodiments.

(207) In some embodiments, operation **620** includes depositing the second set of conductive structures **720** on the back-side of the wafer. In some embodiments, the second set of conductive structures **720** of method **600** includes at least conductive structure **340**, conductive structure **342**, conductive structure **344** or conductive structure **346**.

(208) In some embodiments, operation **620** includes filling the openings in the insulating layer **722** with conductive material, e.g., copper, aluminum, titanium, nickel, tungsten, or other suitable conductive material. In some embodiments, the openings are filled using CVD, PVD, sputtering, ALD or other suitable formation process.

(209) In some embodiments, one or more of the operations of method **600** is not performed. In some embodiments, one or more of the operations of method **600** is repeated. In some embodiments, method **600** is repeated.

(210) FIGS. 7A-7E are cross-sectional views of an integrated circuit, in accordance with one or more embodiments.

(211) FIG. 7A is a cross-sectional view of an integrated circuit **700A**, in accordance with one or more embodiments. In some embodiments, integrated circuit **700A** corresponds to an integrated circuit, such as integrated circuit **300A** or **300B**, following at least operation **602a**, **604a** or **606a**. In some embodiments, integrated circuit **700A** includes an oxide layer **704** on substrate **320**.

(212) FIG. 7B is a cross-sectional view of an integrated circuit **700B**, in accordance with one or more embodiments. In some embodiments, integrated circuit **700B** corresponds to an integrated

circuit, such as integrated circuit **300A** or **300B**, following at least operation **602b**, **604b** or **606b**. In some embodiments, integrated circuit **700B** includes via **706** formed in an opening of at least the oxide layer **704** or the substrate **320**. In some embodiments, integrated circuit **700B** further includes an epitaxial layer **708** over via **706**, the oxide layer **704** and the substrate **320**. In some embodiments, the epitaxial layer **708** is grown in an unfilled portion of the opening of the oxide layer **704**.

(213) FIG. 7C is a cross-sectional view of an integrated circuit **700C**, in accordance with one or more embodiments. In some embodiments, integrated circuit **700C** corresponds to an integrated circuit, such as integrated circuit **300A** or **300B**, following at least operation **612**. In some embodiments, integrated circuit **700C** includes the first set of conductive structures **710**, insulating layer **712** and integrated circuit **700B**. In some embodiments, integrated circuit **700C** includes the first set of conductive structures **710** fabricated in removed portions of insulating layer **712** on the front-side **305** of the wafer **320**.

(214) FIG. 7D is a cross-sectional view of an integrated circuit **700D**, in accordance with one or more embodiments. In some embodiments, integrated circuit **700D** corresponds to an integrated circuit, such as integrated circuit **300A** or **300B**, prior to the wafer thinning of operation **614**. In some embodiments, integrated circuit **700D** includes integrated circuit **700C** flipped over.

(215) FIG. 7E is a cross-sectional view of an integrated circuit **700E**, in accordance with one or more embodiments. In some embodiments, integrated circuit **700E** corresponds to an integrated circuit, such as integrated circuit **300A** or **300B**, following at least operation **620**. In some embodiments, integrated circuit **700E** includes the second set of conductive structures **720**, insulating layer **722** and integrated circuit **700D** (without the removed portion of wafer **320**). In some embodiments, integrated circuit **700E** includes the second set of conductive structures **720** fabricated in removed portions of insulating layer **722** of the wafer **320**.

(216) Other diode types or numbers of diodes, or other transistor types or other numbers of transistors in at least integrated circuit **100**, **200** and **300A-300B** of corresponding FIGS. **1**, **2** and **3A-3B** are within the scope of the present disclosure.

(217) Furthermore, various NMOS or PMOS transistors shown in FIGS. **3A-3B** are of a particular dopant type (e.g., N-type or P-type) and are for illustration purposes. Embodiments of the disclosure are not limited to a particular transistor type, and one or more of the PMOS or NMOS transistors shown in FIGS. **3A-3B** can be substituted with a corresponding transistor of a different transistor/dopant type. Similarly, the low or high logical value of various signals used in the above description is also used for illustration. Embodiments of the disclosure are not limited to a particular logical value when a signal is activated and/or deactivated. Selecting different logical values is within the scope of various embodiments. Selecting different numbers of PMOS transistors in **3A-3B** is within the scope of various embodiments.

(218) One aspect of this description relates to an ESD protection circuit. An electrostatic discharge (ESD) protection circuit includes a first diode, a second diode, an ESD clamp circuit and a first conductive structure on a backside of a semiconductor wafer, and being coupled to a reference voltage supply. In some embodiments, the first diode is in a semiconductor wafer, and coupled between an input output (IO) pad and a first node. In some embodiments, the second diode is in the semiconductor wafer, coupled to the first diode, and coupled between the IO pad and a second node. In some embodiments, the ESD clamp circuit is in the semiconductor wafer, coupled to the first node and the second node, and between the first diode and the second diode. The ESD clamp circuit includes a first signal tap region in the semiconductor wafer. In some embodiments, the first signal tap region is coupled to a reference voltage supply. In some embodiments, the second diode is coupled to and configured to share the first signal tap region with the ESD clamp circuit. In some embodiments, the first conductive structure is coupled to the reference voltage supply, and configured to provide a reference voltage of the reference voltage supply to the first signal tap region.

(219) Another aspect of this description relates to an ESD protection circuit. The ESD protection circuit includes a first diode in a semiconductor wafer, and being coupled to a first pad. In some embodiments, the ESD protection circuit further includes a second diode in the semiconductor wafer, and being coupled to the first diode and the first pad. In some embodiments, the ESD protection circuit further includes an input output (IO) circuit in the semiconductor wafer, being coupled to the first diode, the second diode, and the first pad. In some embodiments, the ESD protection circuit further includes an ESD clamp circuit in the semiconductor wafer, coupled to the first diode by a first node and coupled to the second diode by a second node, the ESD clamp circuit including a first signal tap region, and a second signal tap region coupled to a reference voltage supply. In some embodiments, the second diode is coupled to and configured to share the second signal tap region with the ESD clamp circuit.

(220) Yet another aspect of this description relates to a method of operating an ESD protection circuit. The method includes receiving a first ESD voltage on a first node, the first ESD voltage being greater than a supply voltage of a voltage supply, the first ESD voltage corresponding to a first ESD event. In some embodiments, the method further includes conducting a first ESD current from a first cathode of a first diode to a first signal tap region of an ESD clamp circuit, wherein the ESD clamp circuit is coupled to the first diode, the first signal tap region is coupled to the voltage supply, and the first diode is coupled to and configured to share the first signal tap region with the ESD clamp circuit. In some embodiments, the method further includes discharging the first ESD current of the first ESD event by the ESD clamp circuit.

(221) A number of embodiments have been described. It will nevertheless be understood that various modifications may be made without departing from the spirit and scope of the disclosure. For example, various transistors being shown as a particular dopant type (e.g., N-type or P-type Metal Oxide Semiconductor (NMOS or PMOS)) are for illustration purposes. Embodiments of the disclosure are not limited to a particular type. Selecting different dopant types for a particular transistor is within the scope of various embodiments. The low or high logical value of various signals used in the above description is also for illustration. Various embodiments are not limited to a particular logical value when a signal is activated and/or deactivated. Selecting different logical values is within the scope of various embodiments. In various embodiments, a transistor functions as a switch. A switching circuit used in place of a transistor is within the scope of various embodiments. In various embodiments, a source of a transistor can be configured as a drain, and a drain can be configured as a source. As such, the term source and drain are used interchangeably. Various signals are generated by corresponding circuits, but, for simplicity, the circuits are not shown.

(222) Various figures show capacitive circuits using discrete capacitors for illustration. Equivalent circuitry may be used. For example, a capacitive device, circuitry or network (e.g., a combination of capacitors, capacitive elements, devices, circuitry, or the like) can be used in place of the discrete capacitor. The above illustrations include exemplary steps, but the steps are not necessarily performed in the order shown. Steps may be added, replaced, changed order, and/or eliminated as appropriate, in accordance with the spirit and scope of disclosed embodiments.

(223) The foregoing outlines features of several embodiments so that those skilled in the art may better understand the aspects of the present disclosure. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions, and alterations herein without departing from the spirit and scope of the present disclosure.

Claims

1. An electrostatic discharge (ESD) protection circuit, comprising: a first diode in a semiconductor wafer, and being coupled between an input output (IO) pad and a first node; a second diode in the semiconductor wafer, being coupled to the first diode, and being coupled between the IO pad and a second node; an ESD clamp circuit in the semiconductor wafer, being coupled to the first node and the second node, and being between the first diode and the second diode, the ESD clamp circuit including a first signal tap region in the semiconductor wafer, the first signal tap region being coupled to a reference voltage supply, and the second diode being coupled to and configured to share the first signal tap region with the ESD clamp circuit; and a first conductive structure on a backside of the semiconductor wafer, and being coupled to at least the reference voltage supply, and configured to provide a reference voltage of the reference voltage supply to the first signal tap region.
2. The ESD protection circuit of claim 1, wherein the ESD clamp circuit further includes a second signal tap region in the semiconductor wafer, the second signal tap region being coupled to a voltage supply different from the reference voltage supply, the first diode being coupled to and configured to share the second signal tap region with the ESD clamp circuit.
3. The ESD protection circuit of claim 2, further comprising: a second conductive structure on the backside of the semiconductor wafer, and being coupled to at least the voltage supply, and configured to provide a supply voltage of the voltage supply to the second signal tap region.
4. The ESD protection circuit of claim 3, wherein the first conductive structure is further coupled to the first signal tap region; and the second conductive structure is further coupled to the second signal tap region.
5. The ESD protection circuit of claim 1, wherein at least the first diode or the second diode does not include a signal tap region.
6. The ESD protection circuit of claim 1, wherein the first diode is a first nanosheet vertical well diode; the second diode is a second nanosheet vertical well diode; and the ESD clamp circuit is at least one nanosheet transistor device.
7. The ESD protection circuit of claim 1, wherein the IO pad comprises: a second conductive structure coupled to a first anode of the first diode, and being located on the backside of the semiconductor wafer; and a third conductive structure coupled to a second anode of the second diode, and being located on the backside of the semiconductor wafer.
8. The ESD protection circuit of claim 1, further comprising: an internal circuit in the semiconductor wafer, and being coupled to the first diode, the second diode, and the IO pad.
9. An electrostatic discharge (ESD) protection circuit, comprising: a first diode in a semiconductor wafer, and being coupled to a first pad; a second diode in the semiconductor wafer, and being coupled to the first diode and the first pad; an input output (IO) circuit in the semiconductor wafer, being coupled to the first diode, the second diode, and the first pad; and an ESD clamp circuit in the semiconductor wafer, coupled to the first diode by a first node and coupled to the second diode by a second node, the ESD clamp circuit including a first signal tap region, and a second signal tap region coupled to a reference voltage supply, wherein the second diode is coupled to and configured to share the second signal tap region with the ESD clamp circuit.
10. The ESD protection circuit of claim 9, wherein the first diode comprises: a first anode in the semiconductor wafer; and a first cathode in the semiconductor wafer, being over the first anode and being coupled to the first signal tap region by the first node.
11. The ESD protection circuit of claim 10, wherein the first diode further comprises: a second cathode in the semiconductor wafer, being over the first anode and being coupled to the first signal tap region and the first cathode by the first node.
12. The ESD protection circuit of claim 11, wherein the second diode comprises: a second anode in

the semiconductor wafer; and a third cathode in the semiconductor wafer, being over the second anode and being coupled to the second signal tap region by the second node.

13. The ESD protection circuit of claim 12, wherein the second diode further comprises: a fourth cathode in the semiconductor wafer, being over the second anode and being coupled to the second signal tap region and the third cathode by the second node.

14. The ESD protection circuit of claim 13, further comprising: a first conductive structure located on a backside of the semiconductor wafer, and being between a voltage supply and the first signal tap region; and a second conductive structure located on the backside of the semiconductor wafer, and being between the reference voltage supply and the second signal tap region, the second conductive structure being separated from the first conductive structure in a first direction.

15. The ESD protection circuit of claim 14, wherein the first pad comprises: a third conductive structure located on the backside of the semiconductor wafer, and being coupled to the first anode of the first diode; and a fourth conductive structure located on the backside of the semiconductor wafer, and being coupled to the second anode of the second diode, the fourth conductive structure being separated from the third conductive structure in the first direction.

16. The ESD protection circuit of claim 9, wherein the ESD clamp circuit is between the first diode and the second diode.

17. A method of operating an electrostatic discharge (ESD) protection circuit, the method comprising: receiving a first ESD voltage on a first node, the first ESD voltage being greater than a supply voltage of a voltage supply, the first ESD voltage corresponding to a first ESD event; conducting a first ESD current from a first cathode of a first diode to a first signal tap region of an ESD clamp circuit, wherein the ESD clamp circuit is coupled to the first diode, the first signal tap region is coupled to the voltage supply, and the first diode is coupled to and configured to share the first signal tap region with the ESD clamp circuit; and discharging the first ESD current of the first ESD event by the ESD clamp circuit.

18. The method of claim 17, wherein discharging the first ESD current of the first ESD event by the ESD clamp circuit comprises: conducting the first ESD current from the first signal tap region to a second signal tap region of the ESD clamp circuit; and conducting the first ESD current from the second signal tap region of the ESD clamp circuit to a second node.

19. The method of claim 18, further comprising: receiving a second ESD voltage on the first node, the second ESD voltage being greater than a reference supply voltage of a reference voltage supply, the second ESD voltage corresponding to a second ESD event; turning on a second diode, thereby conducting a second ESD current from a second anode of the second diode to a second cathode of the second diode; conducting the second ESD current from the second cathode of the second diode to the second signal tap region of the ESD clamp circuit; and discharging the second ESD current of the second ESD event by the ESD clamp circuit.

20. The method of claim 19, wherein discharging the second ESD current of the second ESD event by the ESD clamp circuit comprises: turning on the ESD clamp circuit in response to the second ESD current being received at the second signal tap region of the ESD clamp circuit or a third node; coupling the third node to a fourth node in response to the ESD clamp circuit turning on; conducting the second ESD current from the second signal tap region to the first signal tap region of the ESD clamp circuit; and conducting the second ESD current from the first signal tap region of the ESD clamp circuit to a fifth node.
