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MONOLITHICALLY INTEGRATED VOLTAGE DIVIDER DEVICE BASED ON DEPLETION FIELD EFFECT

Abstract

An integrated circuit (IC) device configured for voltage reduction between an input and an output comprises a plurality of alternatingly doped regions arranged laterally in a lateral direction and alternatingly doped with dopants of opposite types. The alternatingly doped regions comprises an input drift region and an output drift region each doped with a dopant of a first type, wherein the input drift region is connected to the input and the output drift region is connected to the output. The alternatingly doped regions further comprises an inter-gate region and a substrate region of the isolated substrate region each doped with a dopant of a second type, wherein the inter-gate region is laterally interposed between the input and output drift regions.

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Background/Summary

INCORPORATION BY REFERENCE TO ANY PRIORITY APPLICATIONS [0001] Any and all applications for which a foreign or domestic priority claim is identified in the Application Data Sheet as filed with the present application are hereby incorporated by reference under 37 CFR 1.57. [0002] This application claims priority to U.S. Provisional Application No. 63/268,585, filed Feb. 25, 2022, U.S. Provisional Application No. 63/268,590, filed Feb. 25, 2022, U.S. Provisional Application No. 63/268,588, filed Feb. 25, 2022, U.S. Provisional Application No. 63/268,587, filed Feb. 25, 2022, and U.S. Provisional Application No. 63/268,519 filed Feb. 25, 2022. The entire content of each of the applications referenced in this paragraph is hereby incorporated by reference herein for all purposes and made a part of this specification.

BACKGROUND

Technical Field

[0003] The disclosed technology relates generally to integrated circuits and more particularly to monolithically integrated high performance transistors and high voltage devices.

Description of Related Art

[0004] Some integrated circuit (IC) devices include a combination of one or more different types of semiconductor devices, such as complementary metal oxide semiconductor (CMOS) devices, bipolar devices and double diffused metal oxide semiconductor (DMOS) devices. Bipolar-CMOS-DMOS (BCDMOS) devices refer to IC devices that include features of each of bipolar, CMOS and DMOS devices, and can combine characteristics thereof. For example, bipolar devices can provide precise analog functions, CMOS devices can provide digital design and DMOS devices can provide power and high-voltage elements. The combination of these different device technologies can bring a combination of these and other advantages including high speed and high voltage operation, improved reliability, reduced electromagnetic interference and smaller chip area. BCDMOS devices find application in a broad range of products and applications in the fields of power management, analog data acquisition and power actuators, to name a few.

SUMMARY

[0005] In one aspect, an integrated circuit (IC) device comprises a metal-oxide-semiconductor (MOS) transistor comprising a gate stack formed over a channel region thereof and a bipolar junction transistor (BJT) comprising a layer stack formed over a collector region thereof. The gate stack and the layer stack have one or more corresponding layers having a common physical dimension.

[0006] In another aspect, an integrated circuit (IC) device comprises a metal-oxide-semiconductor (MOS) transistor comprising a gate stack formed over a channel region thereof and a bipolar junction transistor (BJT) comprising a layer stack formed over a collector region thereof. The gate stack and the layer stack have corresponding spacer structures formed on sidewalls thereof having a common physical dimension.

[0007] In another aspect, an integrated circuit (IC) device comprises a metal-oxide-semiconductor (MOS) transistor comprising a gate stack formed over a channel region thereof and a bipolar junction transistor (BJT) comprising a layer stack formed over a collector region thereof. The MOS transistor and the BJT have corresponding implanted diffusion regions having a common implanted

dopant profile.
[0008] In another aspect, an integrated circuit (IC) device comprises a metal-oxide-semiconductor (MOS) transistor and a bipolar junction transistor (BJT) formed in a common semiconductor substrate. The BJT comprises a collector region electrically connected to a high voltage potential divider substrate region in series and physically separated therefrom by an isolation structure. The BJT further comprises a layer stack comprising a conductive field plate formed over the collector region.
[0009] In another aspect, an integrated circuit (IC) device comprises a metal-oxide-semiconductor (MOS) transistor and a bipolar junction transistor (BJT) formed in a common semiconductor substrate. The BJT comprises a collector region electrically connected to a high voltage potential divider substrate region in series and physically separated therefrom by an isolation structure. The collector region and the high voltage potential divider substrate region are electrically connected through one or more metallization levels formed above a major surface of the common semiconductor substrate.
[0010] In another aspect, an integrated circuit (IC) device comprises a metal-oxide-semiconductor (MOS) transistor and a bipolar junction transistor (BJT) formed in a common semiconductor substrate. The BJT comprises a collector region electrically connected to a high voltage potential divider substrate region in series and physically separated therefrom by an isolation structure. The high voltage potential divider substrate region is configured to drop >50% of a combined voltage applied across the BJT and the high voltage potential divider substrate region.
[0011] In another aspect, an integrated circuit (IC) device comprises a metal-oxide-semiconductor (MOS) transistor and a lateral double-diffused metal-oxide-semiconductor (LDMOS) transistor formed in a common semiconductor substrate. The LDMOS transistor comprises an extended drain drift region that is physically separated from a channel region of the LDMOS transistor by an isolation structure. A gate stack of the MOS transistor and a gate stack of the LDMOS transistor have one or more corresponding layers having a common physical dimension.
[0012] In another aspect, an integrated circuit (IC) device comprises a metal-oxide-semiconductor (MOS) transistor and a lateral double-diffused metal-oxide-semiconductor (LDMOS) transistor formed in a common semiconductor substrate. The LDMOS transistor comprises an extended drain drift region that is physically separated from a channel region of the LDMOS transistor by an isolation structure. The MOS transistor and the LDMOS transistor have implanted diffusion regions having a common implanted dopant profile.
[0013] In another aspect, an integrated circuit (IC) device comprises a metal-oxide-semiconductor (MOS) transistor and a lateral double-diffused metal-oxide-semiconductor (LDMOS) transistor formed in a common semiconductor substrate. The LDMOS transistor comprises an extended drain drift region that is physically separated from a channel region of the LDMOS transistor by an isolation structure. The extended drain drift region comprising a conductive field plate formed thereover.
[0014] In another aspect, an integrated circuit (IC) device comprises a metal-oxide-semiconductor (MOS) transistor and one or both of a bipolar junction transistor (BJT) and a lateral double-diffused metal-oxide-semiconductor (LDMOS) transistor formed in a common silicon substrate. The IC device additionally comprises a high voltage potential divider region formed above a major surface of the common semiconductor substrate and integrated in a back-end-of-line (BEOL) of the IC device. The high voltage potential divider region is formed of a wide bandgap semiconductor material.
[0015] In another aspect, an integrated circuit (IC) device comprises a metal-oxide-semiconductor (MOS) transistor and one or both of a bipolar junction transistor (BJT) and a lateral double-diffused metal-oxide-semiconductor (LDMOS) transistor formed in a common silicon substrate. The IC device additionally comprises a high voltage potential divider region formed above a major surface of the common semiconductor substrate and integrated in a back-end-of-line (BEOL) of the

IC device. The high voltage potential divider region comprises a major portion comprising a lightly doped semiconductor region.

[0016] In another aspect, an integrated circuit (IC) device comprises a metal-oxide-semiconductor (MOS) transistor and one or both of a bipolar junction transistor (BJT) and a lateral double-diffused metal-oxide-semiconductor (LDMOS) transistor formed in a common silicon substrate. The IC device additionally comprises a high voltage potential divider region formed above a major surface of the common semiconductor substrate and integrated in a back-end-of-line (BEOL) of the IC device. In operation, the high voltage potential divider region is configured to drop a higher voltage relative to at least the MOS transistor.

[0017] In another aspect, a lateral bipolar junction transistor (BJT), comprises an emitter region formed in a base well, a lightly doped collector region separated in a lateral direction from the base well by a drift region doped with a dopant of a same type at a lower dopant concentration relative to the lightly doped collector region. The lateral BJT additionally comprises a layer stack formed on the drift region where a boundary of the base well or the emitter region is aligned, in a vertical direction crossing the lateral direction, with an edge of the layer stack.

[0018] In another aspect, a lateral bipolar junction transistor (BJT), comprises an emitter region formed in a base well, a lightly doped collector region separated in a lateral direction from the base well by a drift region doped with a dopant of a same type at a lower dopant concentration relative to the lightly doped collector region. The lateral BJT additionally comprises a layer stack formed on the drift region having a spacer formed on a sidewall thereof, where a base length of the lateral BJT, extending in the lateral direction between the emitter region and the drift region, is defined by a lateral width of a bottom portion of the spacer formed on a sidewall of the layer stack.

[0019] In another aspect, a lateral bipolar junction transistor (BJT) comprises an emitter region formed in a base well, and a heavily doped collector region separated in a lateral direction from the base well by a drift region doped with a dopant of a same type at a lower dopant concentration relative to the heavily doped collector region. The lateral BJT additionally comprises a layer stack formed at least on a first lateral section of the drift region, the layer stack including a conductive reduced surface field (RESURF) layer.

[0020] In another aspect, an integrated circuit (IC) device, comprises a metal-oxide-semiconductor (MOS) transistor comprising a heavily doped (HD) drain region, a gate stack, a drain region extension extending in a lateral direction from the HD drain region to an edge of the gate stack, and at least one drain field plate extending over at least 20% of a length of the drain region extension. Additionally the integrated circuit (IC) device comprises, a bipolar junction transistor (BJT) comprising a heavily doped (HD) collector region, a layer stack, a drift region extension extending in the lateral direction from the HD collector region to an edge of the layer stack, and at least one field plate extending over at least 20% of the drift region extension where at least one drain field plate and at least one field plate have at least one common physical dimension.

[0021] In another aspect, an integrated circuit (IC) device, comprises, a metal-oxide-semiconductor (MOS) transistor comprising a heavily doped (HD) drain region, a gate stack, a drain region extension extending in a lateral direction from the HD drain region to an edge of the gate stack, and a thick dielectric layer extending over the drain region extension. Additionally the integrated circuit (IC) device comprises a bipolar junction transistor (BJT) comprising a heavily doped (HD) collector region, a layer stack, a drift region extension extending in the lateral direction from the HD collector region to an edge of the layer stack, and a thick isolating dielectric layer extending over the drift region extension, where the thick dielectric layer and the thick isolating dielectric layer have at least one common physical dimension.

[0022] In another aspect, an integrated circuit (IC) device comprises a metal-oxide-semiconductor (MOS) transistor comprising a heavily doped (HD) drain region, and a gate stack and a drain region extension extending in a lateral direction from the HD drain region to an edge of the gate stack, the gate stack comprising a gate layer extending over a gate dielectric layer and a portion of

the drain region extension. Additionally the integrated circuit (IC) device, comprises a bipolar junction transistor (BJT) comprising a heavily doped (HD) collector region, a layer stack and a drift region extension extending in the lateral direction from the HD collector region to an edge of the layer stack, and a reduced surface field (RESURF) layer extending over a RESURF dielectric layer and a portion of the drift region extension, where the gate layer and the RESURF layer have least one common physical dimension.

[0023] In another aspect, a bipolar junction transistor (BJT) formed in a substrate, the BJT comprises a base well, an emitter region formed in the base well, a heavily doped (HD) collector region separated in a lateral direction from the base well by a drift region, and a first conductive field plate disposed over a first lateral section of the drift region spanning greater than 20% of a length of the drift region in the lateral direction, where the emitter region, the drift region, and the HD collector region have a same polarity that is opposite to a polarity of the base well.

[0024] In another aspect, a bipolar junction transistor (BJT) formed in a substrate, the BJT comprises a base well, an emitter region formed in the base well; and a heavily doped (HD) collector region separated in a lateral direction from the base well by a drift region having the HD collector region formed therein. The drift region has a lower dopant concentration relative to that of the HD collector region and of the base well and the emitter region, the drift region, and the HD collector region have a same polarity that is opposite to a polarity of the base well.

[0025] In another aspect, a bipolar junction transistor (BJT) formed in a substrate, the BJT comprises a base well, an emitter formed in the base well, a heavily doped (HD) collector region separated in a lateral direction from the base well by a drift region, and a thick dielectric layer disposed on a first lateral section of the drift region. The first lateral section is longer than 20% of a length of the drift region in the lateral direction, and the emitter region, drift region, and the HD collector region have a same polarity opposite to a polarity of the base well.

[0026] In another aspect, an integrated circuit (IC) device configured for voltage reduction between an input and an output, where the IC device comprises an isolated substrate region formed in a semiconductor substrate while being electrically isolated therefrom in vertical and lateral directions, the isolated substrate region having formed therein a plurality of alternatingly doped regions arranged laterally in a lateral direction and alternatingly doped with dopants of opposite types. The alternatingly doped regions comprises an input drift region and an output drift region each doped with a dopant of a first type, where the input drift region is connected to the input and the output drift region is connected to the output, an inter-gate region and a substrate region of the isolated substrate region each doped with a dopant of a second type, where the inter-gate region is laterally interposed between the input and output drift regions. The heavily doped first gate region formed within the inter-gate region where the input drift region is elongated to have a first lateral length along the lateral direction that is longer than a second lateral length of the inter-gate region by at least a factor of two.

[0027] In another aspect, an integrated circuit (IC) device configured for voltage reduction between an input and an output where the IC device comprises an isolated substrate region formed in a substrate while being electrically isolated therefrom in vertical and lateral directions, the isolated substrate region having formed therein a plurality of alternatingly doped regions arranged laterally in a lateral direction and alternatingly doped with dopants of opposite types. The alternatingly doped regions comprises an input drift region and an output drift region each doped with a dopant of a first type, where the input drift region is connected to the input and the output drift region is connected to the output, and an inter-gate region and a substrate region of the isolated substrate region each doped with a dopant of a second type, where the inter-gate region is laterally interposed between the input and output drift regions. The inter-gate region has a dopant concentration that is lower than that of the input drift region, the output drift region and the substrate region, and a heavily doped first gate region formed within the inter-gate region.

[0028] In another aspect, an integrated circuit (IC) device configured for voltage reduction between

an input and an output, where the IC device comprises an isolated substrate region formed in a substrate while being electrically isolated therefrom in vertical and lateral directions, the isolated substrate region having formed therein a plurality of alternatingly doped regions arranged laterally in a lateral direction and alternatingly doped with dopants of opposite types. The alternatingly doped regions comprise an input drift region and an output drift region each doped with a dopant of a first type, where the input drift region is connected to the input and the output drift region is connected to the output, an inter-gate region and a substrate region of the isolated substrate region each doped with a dopant of a second type. The inter-gate region is laterally interposed between the input and output drift regions. Additionally the integrated circuit (IC) device comprises a dielectric layer covering the input drift region and at least one conductive field plate extending above the dielectric layer along the lateral direction, and a heavily doped (HD) first gate region formed within the inter-gate region.

[0029] In another aspect, an integrated circuit (IC) device comprises at least one low voltage active semiconductor device formed in a first substrate region of a semiconductor substrate; and a depletion field effect potential divider (DFE-PD) formed in a second substrate region of the semiconductor substrate and configured to reduce a high voltage input signal received from a high voltage node to generate a low voltage output signal, and to provide the low voltage output signal to the low voltage active semiconductor device as an input signal thereto. The low voltage active semiconductor device and the DFE-PD are physically separated while being electrically connected in series, and the first and the second substrate regions are electrically separated by an isolation structure.

[0030] In another aspect, an integrated circuit (IC) device, comprises at least one low voltage active semiconductor device formed in a first substrate region of a semiconductor substrate; and a depletion field effect potential divider (DFE-PD) formed in a second substrate region of the semiconductor substrate and configured to reduce a high voltage input signal received from a high voltage node to generate a low voltage output signal, and to provide the low voltage output signal to the low voltage active semiconductor device as an input signal thereto. The DFE-PD comprises a plurality of alternatingly doped regions arranged laterally in a lateral direction and alternatingly doped with dopants of opposite types. The alternatingly doped regions comprises an input drift region and an output drift region each doped with a dopant of a first type, where the input drift region is connected to the input and the output drift region is connected to the output, and an inter-gate region laterally interposed between the input and output drift regions, where the inter-gate region and the second substrate region are doped with a dopant of a second type, and a heavily doped first gate region formed within the inter-gate region.

[0031] In another aspect, an integrated circuit (IC) device, comprises at least one low voltage active device formed in a semiconductor substrate; and a depletion field effect potential divider (DFE-PD) formed above a major surface of the semiconductor substrate and separated therefrom by a dielectric layer, the DFE-PD configured to scale a high voltage input signal received from a high voltage node to a low voltage output signal, and to provide a low voltage signal to the low voltage active device as an input signal thereto. The DFE-PD comprises a doped semiconductor region extending along a lateral direction parallel to the major surface of the substrate between a heavily doped (HD) input region and a heavily doped (HD) output region, and a depletion control region formed within the doped semiconductor region and oppositely doped relatively to a remainder of the doped semiconductor region where the DFE-PD and the low voltage active device are electrically connected by an electrical connection.

[0032] In another aspect, an integrated circuit (IC) device, comprises at least one low voltage active device formed in a semiconductor substrate; and a depletion field effect potential divider (DFE-PD) formed above a major surface of the semiconductor substrate and separated therefrom by a dielectric layer, the DFE-PD configured to scale a high voltage input signal received from a high voltage node to a low voltage output signal, and to provide a low voltage signal to the low voltage

active device as an input signal thereto. The DFE-PD comprises a doped semiconductor region laterally extending along a lateral direction parallel to the major surface of the substrate between a heavily doped (HD) input region that receives the low voltage output signal and a heavily doped (HD) output region that outputs the low voltage signal. Additionally, The DFE-PD comprises a depletion control region formed within the doped semiconductor region and oppositely doped relatively to a remainder of the doped semiconductor region, and at least one conductive field plate laterally extending over the doped semiconductor region and electrically connected to the low voltage active device by an electrical connection formed at least partly above the semiconductor substrate.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] The summary above, as well as the following detailed description of illustrative embodiments, is better understood when read in conjunction with the appended drawings. For the purpose of illustrating the present disclosure, exemplary constructions of the disclosure are shown in the drawings. Moreover, those in skilled in the art will understand that the drawings are not to scale. Wherever possible, like elements have been indicated by identical numbers. The detailed description of embodiments and the embodiments set forth in the drawings present various descriptions of specific embodiments of the invention. However, the invention can be embodied in a multitude of different ways. It will be understood that certain embodiments can include more elements than illustrated in a drawing and/or a subset of the elements illustrated in a drawing. Further, some embodiments can incorporate any suitable combination of features from two or more drawings. The present disclosure is not limited to specific methods and apparatus disclosed herein.

[0034] Embodiments of the present disclosure will now be described, by way of example only, with reference to the following patent diagrams wherein:

[0035] FIG. **1**A schematically illustrates a multi-die electronic platform that includes bipolar, CMOS, and DMOS devices mounted as multiple dies on a single substrate.

[0036] FIG. **1**B is a block diagram illustrating the monolithically integrated BCDMOS (or superset) design concept.

[0037] FIG. **2** schematically illustrates a side cross-sectional view of a bipolar-CMOS (BiCMOS) integrated circuit (IC) in accordance with certain embodiments disclosed herein.

[0038] FIG. **3**A schematically illustrates a side cross-sectional view of an MOS transistor with extended drain drift region and field plates.

[0039] FIG. **3**B schematically illustrates a side cross-sectional view of a lateral bipolar junction transistor (BJT) with extended drift region and field plates, in accordance with certain embodiments disclosed herein.

[0040] FIG. **4**A schematically illustrates a side cross-sectional view of a MOS transistor with extended drain region and close up views of the source region (left) and the extended drain region (right).

[0041] FIG. **4**B schematically illustrates a side cross-sectional view of a lateral bipolar junction transistor (L-BJT) with an extended drift region and close up views of the base/emitter regions (left) and extended collector region (right), in accordance with certain embodiments disclosed herein.

[0042] FIG. **5**A schematically illustrates a side cross-sectional view of a laterally isolated potential divider (PD) electrically connected to a MOSFET in accordance with certain embodiments disclosed herein.

[0043] FIG. **5**B schematically illustrates a side cross-sectional view of a laterally isolated PD electrically connected to a vertical bipolar junction transistor (V-BJT) in accordance with certain

embodiments disclosed herein.
[0044] FIG. **5**C schematically illustrates a side cross-sectional view of a laterally isolated potential divider electrically connected to a lateral bipolar junction transistor (L-BJT) in accordance with certain embodiments disclosed herein.
[0045] FIG. **6**A schematically illustrates a three dimensional (3D) view of a vertically isolated PD in accordance with certain embodiments disclosed herein.
[0046] FIG. **6**B schematically illustrates a 3D view of a PD fabricated in the backend-of-the-line (BEOL) of an IC with respect to a substrate that includes BCDMOS devices electrically connected to the PD.
[0047] FIG. **7**A schematically illustrates a side cross-sectional view of an example L-BJT in accordance with certain embodiments disclosed herein.
[0048] FIG. **7**B schematically illustrates a side cross-sectional view of a MOS transistor.
[0049] FIG. **7**C schematically illustrates a side cross-sectional view of another disclosed embodiment of L-BJT.
[0050] FIG. **7**D schematically illustrates a side cross-sectional view of an LDMOS transistor.
[0051] FIG. **8**A schematically illustrates a 3D view of another disclosed embodiment of L-BJT.
[0052] FIG. **8**B schematically illustrates a top view of the L-BJT shown in FIG. **8**A.
[0053] FIG. **8**C schematically illustrates a side cross-sectional view of another embodiment of L-BJT.
[0054] FIG. **8**D schematically illustrates a top view of the L-BJT shown in FIG. **8**C.
[0055] FIG. **9**A schematically illustrates a side cross-sectional view of an L-BJT having a dedicated base spacer in accordance with certain embodiments disclosed herein.
[0056] FIG. **9**B schematically illustrates a side cross-sectional view of an L-BJT having an elongated emitter region in accordance with certain embodiments disclosed herein.
[0057] FIG. **9**C schematically illustrates a side cross-sectional view of an L-BJT having a vertical emitter section in accordance with certain embodiments disclosed herein.
[0058] FIG. **9**D schematically illustrates a side cross-sectional view of an L-BJT having an elongated emitter region and a vertical emitter section in accordance with certain embodiments disclosed herein.
[0059] FIG. **9**E schematically illustrates a side cross-sectional view a vertically and laterally isolated L-BJT in accordance with certain embodiments disclosed herein.
[0060] FIG. **9**F schematically illustrates a side cross-sectional view of an L-BJT having a thermally diffused base region in accordance with certain embodiments disclosed herein.
[0061] FIGS. **10**A-**10**E schematically illustrate selected fabrication steps for fabricating an L-BJT in accordance with certain embodiments disclosed herein.
[0062] FIG. **10**F schematically illustrates a fabrication step for fabricating an L-BJT having an elongated emitter region in accordance with certain embodiments disclosed herein.
[0063] FIGS. **11**A-**11**E schematically illustrate selected fabrication steps for fabricating an L-BJT in accordance with certain other embodiments disclosed herein.
[0064] FIG. **11**F schematically illustrates a fabrication step for fabricating an L-BJT having an elongated emitter region in accordance with certain other embodiments disclosed herein.
[0065] FIGS. **12**A-**12**C schematically illustrate selected fabrication steps for fabricating an L-BJT having a vertical emitter section in accordance with certain embodiments disclosed herein.
[0066] FIGS. **12**D-**12**F schematically illustrate selected fabrication steps for fabricating an L-BJT having a vertical emitter section region in accordance with certain other embodiments disclosed herein.
[0067] FIGS. **13**A-**13**E schematically illustrate selected fabrication steps for fabricating an L-BJT having a thermally diffused base region in accordance with certain embodiments disclosed herein.
[0068] FIGS. **14**A-**14**E schematically illustrate selected fabrication steps for fabricating an L-BJT having a thermally diffused base region in accordance with certain embodiments disclosed herein.

[0069] FIG. **15**A schematically illustrates a cross-sectional view of the L-BJT shown in FIG. **9**D and variation of the voltage and electric field along its drift region.
[0070] FIG. **15**B schematically illustrates a cross-sectional view of the L-BJT shown in FIG. **7**C and variation of the voltage and electric field along its drift region.
[0071] FIG. **16**A schematically illustrates a cross-sectional view of an embodiment of an L-BJT having an extended drift region with three field plates, and a schematic dopant profile thereof.
[0072] FIG. **16**B schematically illustrates a cross-sectional view of the L-BJT shown in FIG. **16**A and variation of the electric field along its extended drift region.
[0073] FIG. **16**C schematically illustrates a cross-sectional view of an L-BJT having an extended drift region with four field plates thereover, and variation of the voltage and electric field along its extended drift region.
[0074] FIG. **17** schematically illustrates a graph illustrating approximate operating voltages supported by several L-BJT designs as a function of the length of the corresponding drift regions.
[0075] FIG. **18** schematically illustrates a side cross-sectional view of an L-BJT having an extended drift region that is fully isolated using a buried oxide layer and trench isolation.
[0076] FIG. **19** schematically illustrates a side cross-sectional view an L-BJT with isolated extended drift region fully isolated using trench isolation.
[0077] FIG. **20** schematically illustrates the depletion region of the L-BJT shown in FIG. **19** at three different magnitudes of input voltages.
[0078] FIG. **21** schematically illustrates an L-BJT with an extended drift region and vertically separated drift region extension.
[0079] FIG. **22**A schematically illustrates a cross-sectional view of a semiconductor device structure configured for voltage reduction with output saturation, and the corresponding voltage transfer function in an open ended output configuration.
[0080] FIG. **22**B schematically illustrates a cross-sectional view of another semiconductor device structure configured for voltage reduction, without output saturation and with slope change, and the corresponding voltage transfer function in an open ended output configuration.
[0081] FIG. **22**C schematically illustrates a cross-sectional view of another semiconductor device structure configured for linear or near linear voltage reduction with non-zero punch-through voltage, and the corresponding voltage transfer function in an open ended output configuration.
[0082] FIG. **22**D schematically illustrates a cross-sectional view of another semiconductor device structure configured for linear or near linear voltage reduction with zero punch-through voltage, and the corresponding voltage transfer function in an open ended output configuration.
[0083] FIG. **22**C schematically illustrates a cross-sectional view of another semiconductor device structure for voltage reduction with, non-zero punch-through voltage, and the corresponding voltage transfer function in an open ended output configuration.
[0084] FIGS. **23**A-**23**B schematically illustrate voltage transformation through an inter-gate region and the distribution and evolution of electric charge and electric field in the inter-gate region.
[0085] FIGS. **24**A-**24**B schematically illustrate a long (A) and a short (B) inter-gate region showing the impact of the length an inter-gate region on the slope of the corresponding voltage transformation.
[0086] FIG. **25**A schematically illustrates a cross-sectional view of a depletion field effect potential divider (DFE-PD) with an extended drift region.
[0087] FIG. **25**B is plot of voltage variation along the DFE-PD shown in FIG. **25**A for various values of the input voltage.
[0088] FIG. **26**A is plot of output voltage generated by a DFE-PD as a function of the input voltage provided to DFE-PD.
[0089] FIG. **26**B is plot of output current per unit length for a DFE-PD as a function of the input voltage provided to DFE-PD.
[0090] FIG. **27**A schematically illustrates a cross-sectional view of a DFE-PD with a gate region on

the input side.
[0091] FIG. **27**B schematically illustrates a cross-sectional view of a DFE-PD with a gate region on the input side and the output side.
[0092] FIG. **28**A schematically illustrates a side cross-sectional view of a DFE-PD having field plates on input region fabricated on a substrate and voltage variation along the DFE-PD for several values of the input voltage.
[0093] FIG. **28**B is plot of output voltage generated by a DFE-PD as a function of the input voltage provided to DFE-PD.
[0094] FIG. **28**C is plot of output current per unit length for a DFE-PD as a function of the input voltage provided to DFE-PD.
[0095] FIG. **28**D schematically illustrates the evolution of the depletion regions in the drift, depletion control, and output regions of the DFE-PD shown in FIG. **28**A, as a function of input voltage.
[0096] FIG. **29** schematically illustrates a side cross-sectional view of another DFE-PD having field plates on input and output regions.
[0097] FIG. **30**A schematically illustrates a cross-sectional view of a laterally isolated DFE-PD electrically connected to a lateral bipolar junction transistor (L-BJT) in accordance with certain embodiments disclosed herein.
[0098] FIG. **30**B schematically illustrates a cross-sectional view of a laterally isolated DFE-PD electrically connected to a MOS transistor in accordance with certain embodiments disclosed herein.
[0099] FIG. **31** schematically illustrates a cross-sectional view of an example high voltage device including electrical connections between a DFE-PD and an L-BJT, fabricated on a common substrate, where the DFE-PD and the L-BJT are electrically connected, while being laterally isolated from each other and vertically isolated from the substrate by a buried dielectric layer.
[0100] FIG. **32** schematically illustrates a cross-sectional view of an example high voltage device including electrical connections between a DFE-PD and an L-BJT, fabricated on a common substrate, where the DFE-PD and L-BJT are electrically connected, while being laterally isolated from each other and vertically isolated and confined by a buried dielectric layer.
[0101] FIG. **33** schematically illustrates a cross-sectional view of an example high voltage device including a DFE-PD that is vertically separated from the substrate and directly connected to an L-BJT.
[0102] FIG. **34** schematically illustrates a cross-sectional view of an example high voltage device including a DFE-PD that is vertically separated from the substrate and is electrically connected to an L-BJT via conductive lines.
[0103] FIG. **35** schematically illustrates a cross-sectional view of an example high voltage device including a DFE-PD that is laterally and vertically isolated from the substrate and is electrically connected to an L-BJT via conductive lines.
[0104] FIG. **36** schematically illustrates a cross-sectional view of another example high voltage device including a DFE-PD that is vertically isolated from the substrate and is electrically connected to an L-BJT via conductive lines.
[0105] FIG. **37** schematically illustrates a cross-sectional view of another example high voltage device including a DFE-PD that is vertically isolated from the substrate and is electrically connected to one or more MOS transistors and BJTs via conductive lines.
[0106] FIG. **38**A-**38**B illustrate an equivalent circuit to a DFE-PD.

DETAILED DESCRIPTION

Introduction: Overview of BDCMOS Process Architecture Platform

[0107] Different types of semiconductor devices with distinct characteristics and uses include bipolar, complementary metal oxide (CMOS), and double diffused MOS (DMOS) devices. For example, bipolar devices (e.g., bipolar transistors) can provide precise and high speed analog

functionalities, CMOS devices can provide high speed and high density digital functionalities, and DMOS devices can support high power and high-voltage operations. Conventional high performance bipolar and CMOS devices operate at relatively low voltages (<5 Volts) while DMOS devices can operate at high voltage (up to 400 Volts). Many applications can benefit from functionalities provided by a monolithically fabricated circuit or device that includes a combination of these devices integrated and interconnected on a single substrate (or chip). An integrated circuit (IC) device that includes a combination of monolithically fabricated bipolar junction device and CMOS devices may be referred to as a BiCMOS device or platform. In some cases, a BiCMOS device or platform that include MOS and DMOS transistors or low and high voltage CMOS devices, may be referred to as a bipolar-CMOS-DMOS (BCDMOS) device or platform.

[0108] However, because bipolar, CMOS, and DMOS devices employ different structural features and design rules, and may need to operate at different voltage levels, fabrication (e.g., monolithic fabrication) of a BiCMOS or BCDMOS device on a common substrate, or a monolithic circuit having BCDMOS devices on a single chip, can be relatively difficult, inefficient, and costly. For example, when CMOS fabrication techniques are used for co-fabricating CMOS transistors (also referred to as MOS transistors) and BJTs having conventional designs, one or both of the BJT and MOS transistor may lose their technical and/or cost competitiveness in order to be co-fabricated on the same platform and using same or substantially the same fabrication processes.

[0109] To avoid the complexities associated with monolithic BiCMOS or BCDMOS platforms, some conventional BCDMOS devices are formed by connecting bipolar, CMOS, and DMOS devices fabricated on separate chips (or dies). FIG. **1**A illustrates an example traditional approach to fabricating BCDMOS devices, which includes a multi-die solution, where different devices are fabricated on separate substrates and combined into a single package or multi-die platform **100**. In many existing fabrication methods, the bipolar devices, the CMOS devices, and the DMOS devices are fabricated on separate dies using different fabrication techniques and then mounted (e.g., surface bonded or soldered) on a common substrate **101**. However, such approach can suffer from many disadvantages, including high cost, high package, hi complexity, inefficient area integration, multi-site manufacturing, and sometime low reliability complexity, to name a few. On the other hand, because these different devices can employ very different physical design rules and thermal budgets among other differences, integrating these devices on the same substrate can involve little synergy and lead to unacceptably long fabrication times.

[0110] Fabricating BCDMOS devices on a single chip where different devices are fabricated (e.g., monolithically fabricated) on the same semiconductor substrate, can offer advantages such as reduced area footprint, reduced fabrication cost, and large scale integration, among others, if substantial process steps can be synergized between different ones of the bipolar devices, the CMOS devices, and the DMOS devices. FIG. **1**B is a block diagram illustrating the concept of monolithically fabricating an analog or mixed analog and digital platform (herein referred to as a superset **102**) comprising at least three transistor having distinct functionalities (e.g., high gain, fast switching, high voltage operation, fast power and/or voltage control, and the like). The superset **102** can control electronic signals (e.g., digital and analog signals) within a wide voltage and power ranges. In some implementations, the transistor technologies may include DMOS, and CMOS, and Complimentary Bipolar (C-Bipolar) transistors. The superset **102** design concept combines various distinctive features and advantages of the different types of devices, including the high switching speed and density (number of devices per unit area) of CMOS transistors (e.g., field effect transistors or FETs), the fast analog power control supported by bipolar junction transistors (BJTs), and the high power and high voltage handling capabilities of DMOS transistors. For example, a CMOS transistor may operate between 3 and 125 Volts, a DMOS transistor may operate between 12 and 225 Volts, and a C-Bipolar transistors may operate between 3 and 36 Volts. However, because the different devices including CMOS, DMOS and bipolar devices are fabricated using very different process technologies, such strategy can still be time and cost inefficient due to, e.g.,

high lithography mask counts and slow factory cycle time. In addition, the process architectures and process flows that are engineered for one application, e.g., with unique voltage nodes, can be highly unadaptable for other applications.
[0111] In principle, the superset **102** can fabricated using currently available or commercialized BCDMOS fabrication platforms or a combination of BCDMOS and JFET fabrication platforms. However, fabrication of such superset based on both technologies may suffer from high fabrication cost, long cycle time, high mask count, and lithography limits among other disadvantages. While combining the existing JFET platforms with BCDMOS platforms may improve the performance of the devices used in the superset **102** (including bipolar devices), it can unavoidably disadvantageously increase the cost, cycle time, and mask count among other disadvantages, compared to BCDMOS.
[0112] While combining DMOS devices with bipolar devices on a single platform may enable high voltage (e.g., >10 Volts) operation of a BCDMOS device, many applications can benefit from or may require high voltage operation of a bipolar device (e.g., a BJT that can handle voltages above 10 Volts, 100 Volts, or even 200 Volts). However, the tradeoff between device features associated with high voltage, high gain (e.g., >100), high speed (e.g., >1 GHz), and linearity (among other parameters), imposes a limit on transistor designs (e.g., BJT designs) that can control high voltage signals at high speeds. Moreover, modifying a low voltage device for high voltage operation while keeping its overall size within an acceptable limit for large scale integration can be very challenging.
[0113] In recognition of these and other challenges with existing BDCMOS fabrication technologies, the disclosed technology provides efficient and synergistic monolithic integration of high performance and high voltage BCDMOS devices, and potential dividers that can be combined with low-voltage devices to enable processing and controlling low and high voltage signals on a single monolithically fabricated circuit. Some of the inventive devices and design methods described herein include, without limitation: [0114] low-voltage (LV) lateral (or lateral) bipolar devices (e.g., BJTs) that can be fabricated using established tools, techniques, and concepts developed for CMOS-based devices and thereby can be monolithically fabricated with CMOS devices (e.g., MOSFETs). [0115] Design concepts for can increase the operating voltage of LV lateral bipolar devices using established techniques and concepts developed for DCMOS-based devices and other methods. [0116] Physically dividing low voltage (5V or less)/high performance regions and high voltage (5-400V) regions of BCDMOS process architectures to design BCDMOS devices having a high voltage region physical electrically separated from a low voltage region.
[0117] Depletion field effect (DFE) potential dividers (PDs) that can be connected in series with one or more low voltage to create high voltage devices. The DFE PDs can be fabricated using established tools, techniques, and concepts developed for CMOS-based devices and thereby can be monolithically fabricated with BCDMOS devices. [0118] On-chip isolation structures and designs for electrically isolating high voltage and low voltage devices monolithically fabricated on a same substrate.
[0119] Various inventive aspects disclosed herein may comprise a purposeful construction of a bipolar device (e.g. a lateral BJT), where at least one feature of the bipolar device has substantially the same physical dimension as a corresponding feature of a MOS device, e.g., because the corresponding features are co-fabricated using masks or process steps that are developed for the same or similar technology node or design rule.
[0120] In various conventional BiCMOS process, BJT's are fabricated vertically to allow control over various device parameters, e.g., the vertical doping profile and the base dimensions (e.g., width and/or thickness of a base region). Such approach requires separate fabrication steps, and masks for fabricating BJTs and MOS transistors on a common substrate and significantly increases the cost, complexity, and cycle time of an IC device.
[0121] Disclosed herein is a first inventive aspect directed to a BiCMOS core process architecture

that facilitates the construction of a high performance, low cost, low voltage, and fast factory cycle time BiCMOS technology platform using existing digital cell libraries and fabrication processes established for CMOS devices. Some of the device designs (e.g., lateral bipolar device designs) described herein can synergistically benefit from fabrication steps used in CMOS fabrication technologies using the same ingredients and elements. As such, bipolar device designs disclosed herein may enable exploiting the precision of CMOS processing, which has been under development for several decades, for fabrication of high performance bipolar devices (e.g., bipolar transistors). In some implementations, the disclosed bipolar devices (e.g., lateral bipolar junction transistors), can be co-fabricated with CMOS devices (e.g., MOS filed effect transistors) through a co-fabrication or parallel fabrication process flows in which one or more fabrication steps may be shared at least partly contemporaneously or simultaneously. In some implementations, the disclosed bipolar devices (e.g., lateral BJTs), can substantially be entirely fabricated independently of the MOS devices, but can still benefit from the accuracy, low cost, and reduced cycle time offered by well-developed and advanced CMOS fabrication techniques.

[0122] An example of BiCMOS platform is an IC device comprising a metal-oxide-semiconductor (MOS) transistor (e.g., a MOS field effect transistor or MOSFET) comprising a gate stack formed over a channel region thereof and a bipolar junction transistor (BJT) comprising a layer stack formed over a collector region thereof. The MOS and bipolar transistors of the disclosed IC device are constructed using some common CMOS process features. As a result, various features of the bipolar devices (e.g., BJTs) are defined using structural features and process steps used for fabricating the MOS devices (e.g., MOSFETs). In some embodiments, implantations for forming lightly and/or highly doped regions of the source and drain regions, the gate region, and the channel region of a CMOS device (e.g., a MOSFET), are used to form the emitter, the base, the collector regions of a bipolar device (e.g., a BJT). As described herein, highly or heavily doped (HD) regions, sometimes denoted as P.sup.++ regions or N.sup.++ regions, can have a peak doping concentration exceeding about 1×10.sup.19 cm.sup.−3, exceeding about 1×10.sup.20 cm.sup.−3, or a value in a range defined by any of these values. In addition, lightly doped (LD) regions, sometimes denoted as N.sup.− or P.sup.− regions, can have a peak doping concentration lower than about 1×10.sup.14 cm.sup.−3 or about 1×10.sup.13 cm.sup.−3. In some cases, a highly or heavily doped (HD) region (e.g., a P.sup.++ or N.sup.++) may comprise an ohmic contact region that provides electrical connection to a region (e.g., for example a region in which the HD region is formed). For example, spacers formed on a sidewalls of the gate stack of a MOSFET, used to define a lightly-doped (LD) drain (LDD) region, is used to define the base length (L.sub.B) of a BJT. In addition, gate contact layers (e.g., silicide layers) and gate layers (e.g., polycrystalline silicon layers) that form the gate stacks of CMOS devices, are used to form field plates, e.g., reduced surface field (RESURF) plates, for a bipolar device (e.g., for increasing its operating voltage). One or both of the spacers and the field plates can advantageously also serve as implant hard masks, as described below.

[0123] An example of a disclosed bipolar device that can be co-fabricated with a CMOS device is a lateral BJT (L-BJT) having an emitter region, a base region, and a collector region that are arranged in a lateral direction parallel to a main surface of a common substrate on which a MOS transistor (e.g., a MOSFET) is fabricated. An L-BJT may comprise a PNP (or NPN) transistor having laterally formed PN (or NP) and NP (or PN) junctions configured to support bipolar transistor operation based on bipolar carrier transport substantially in the lateral direction (path of the bipolar current is substantially in the lateral direction). The L-BJT arrangement results in several corresponding features between the two types of devices and allows for enhanced parallel processing of various fabrication steps between the MOSFET and the BJT. As a result, replacing the conventional vertical BJT design with L-BJT can reduce cycle time by significantly improving the synergy between CMOS and BJT fabrication process flows.

[0124] Some examples of the correspondence between the features are shown in FIG. **2**. FIG. **2**

illustrates a portion of an integrated circuit (IC) device **200** fabricated using a low voltage, high performance BiCMOS architecture and process flow according to embodiments. The IC device **200** can include or both of a PNP lateral bipolar junction transistor (PNP L-BJT) **240** and an n-channel MOS (NMOS) transistor **280** fabricated according to a low voltage, high performance BiCMOS process architecture according to embodiments. The IC **200** can additionally include one or both of a p-channel MOS (PMOS) transistor **230** and an NPN L-BJT **235**. The PMOS transistor **230** has analogous features as the NMOS transistor **280** but with regions comprising opposite polarity types of semiconductors regions compared to corresponding regions of the n-channel NMOS transistor **280**. Similarly, the NPN L-BJT **235** has analogous features as the PNP L-BJT **240** but with regions comprising opposite polarity types of semiconductors regions compared to corresponding regions of the PNP L-BJT **240**. The wells (e.g., the common well **212**) in which the MOS transistors **230**, **280**, and the L-BJTs **240** and **235** are formed, may be generated in a substrate **290** (e.g., a silicon substrate).

[0125] It will be appreciated that, as described herein, while some features may be described in reference to a particular type of MOS transistor (e.g., one of NMOS transistor **280** or PMOS transistor **235**), it will be understood that analogous features, where applicable, may be present in the opposite type of MOS transistor (e.g., the other of NMOS transistor **280** or PMOS transistor **235**). Similarly, while some features may be described in reference to a particular type of BJT (e.g., one of PNP L-BJT **240** or NPN L-BJT **235**), it will be understood that analogous features, where applicable, may be present in the opposite type of BJT (e.g., the other of one of PNP L-BJT **240** or NPN L-BJT **235**).

[0126] In some embodiments, the NMOS transistor **280** can be a field effect (FET) transistor comprising a drain region **209**, a source region **207**, and a gate stack **202***a* formed over a channel region **203** between the drain region **209** and the source region **207**. The gate stack **202***a* includes a gate dielectric and a gate. Additionally, the NMOS transistor **280** may comprise gate spacers **216***a* disposed on opposing sidewalls of the gate stack **202***a*.

[0127] In some implementations, the PNP L-BJT **240** may comprise an emitter region **206**, a base region base **201**, a collector region **211**, and a layer stack **202***b* formed over a portion of the collector region **211** thereof. The emitter region **206** has a first polarity or semiconductor type (e.g., p-type) and is formed in a base well **208** having a second polarity or semiconductor type (e.g., n-type) opposite to the first polarity or semiconductor type.

[0128] According to various embodiments described herein, source and drain regions (e.g., source and drain regions **207**, **209**) of a MOS transistor (e.g., NMOS transistor **280**) may include heavily doped regions. In addition, emitter and collector regions (e.g., emitter region **206** and the collector region **211**) of an L-BJT may be heavily doped region.

[0129] It should be understood, as used herein, polarity of a region (e.g., a semiconductor region) is determined by the polarity of the majority charge carrier in that region, which can in turn be defined by the net doping. So in a p-type region, the net doping is positive such that the majority charge carriers are holes, and in an n-type region, the net doping is negative such that the majority charge carriers are electrons. The majority carriers in a region is a charge carrier whose concentration is greater than that of the opposite charge carrier in that region, or larger than its intrinsic concentration in the absence of doping and the same temperature. As such a p-type region can have p-type dopant and n-type dopant, but the p-type dopant is present at a larger concentration than that of the n-type dopant, resulting in a larger hole concentration compared to electron concentration in that region.

[0130] In some cases, the emitter region **206** may have a higher doping concentration than the base well **208** and the base region **201**. Additionally, the PNP L-BJT **240** may comprise spacers **216***b* disposed on the sidewalls of the layer stack **202***b*. In some embodiments, the layer stack **202***b* may serve as a reduced surface field (RESURF) plate that reduces a lateral component of the E-filed in a drift region **205** of the collector region **211**. The layer stack **202***b* may include a dielectric layer on

the substrate and a conducting layer on the dielectric layer. The emitter region **206**, the base region base **201**, and the collector region **211** are arrange laterally (e.g., along y-axis), such that the bipolar operation of the PNP L-BJT **240** is mainly associated with the carrier transport in the lateral direction. As a result, the base region **201** may comprise a region of the base well **208** having a lateral extension from the collector region **211** to the emitter region **206**, and the base length (L.sub.B) can be defined by a lateral distance from a vertical interface (e.g., along z-axis) between the base well **201** and the collector region **211**, and a vertical interface between the emitter region **206** and the base well **208** closer to the collector region **211** (herein referred to as vertical emitter-base junction). Advantageously, in some embodiments, the base length (L.sub.B), which can significantly affect the performance of the PNP L-BJT **240**, is defined by a lateral width of a bottom or base portion of the spacers **216***b* (e.g., the spacer or spacer portion above the base region **201**), which is in turn defined by the spacer fabrication process. Given that the dimensions of the spacers **216***b* (and the corresponding spacers **216***a*) can be accurately defined using standard CMOS fabrication processes, the base length of the PNP L-BJT **240** can be precisely controlled (or defined) by the co-fabrication process. Thus, the design and structure of an L-BJT not only enables its co-fabrication with MOS transistors on a common substrate, but also enables precise control over its base length (e.g., with a resolution of +5 nm, +3 nm, +1 nm, or sun-nanometer). Such level of control over the base length is close to that of the vertical BJTs used in conventional BiCMOS platforms that require dedicated fabrication processes that cannot be synergistically combined with the MOS transistor fabrication process. In some cases, the base length may be defined by a lateral width of a bottom portion of a spacer. The space may be formed by depositing a polysilicon layer and vertically etching the polysilicon layer to provide desired bottom thickness. As such the width of a bottom portion of the spacer (and thereby the base length) may be precisely defined by controlling the polysilicon thickness (by controlling its growth time) and the etching time.

[0131] In some examples, the entire structure of an L-BJT (base well and emitter region therein, layer stack, and the collector region) may be fabricated in and/or on a common well. In some other examples, such as PNP L-BJT **240**, an L-BJT may be partially formed in a common well **212** and a second region (e.g., a second well) **214** comprising a semiconductor having opposite dopant types, and/or an opposite polarity compared to the common well **212**. In such examples, the common well **212** and the second region **214** may have an interface under the base well **208** such that a first portion of the base well **208** shares an interface with the common well **210** and a second portion of the base well **208** shares an interface with the second well. In some cases, a vertical interface between the common well **212** and the second region **214** can be aligned with the vertical emitter-base junction of the PNP L-BJT **240**. In some cases, the PNP L-BJT **240** may include a highly doped (HD) base region (not shown) disposed on the base well **208** to provide an ohmic contact to the base well **208** and the base region **201** therein.

[0132] Still referring to FIG. **2**, in the example shown, the NMOS transistor **280** and the MOS transistor **230** are fabricated in the common well **212** and a second well **214**, respectively. The PNP L-BJT **240** is partially fabricated in the common well **212** and the second well **214**, and the NPN L-BJT **235** is fabricated in third well **215** and the common well **212**. The second well **214** and the third well **215** have the same polarity (e.g., n-type) and the common well **212** has a polarity opposite to that of the second well **214** and the third well **215**.

[0133] According to various aspects, the MOS transistors **280**, **230** and the L-BJTs **240**, **235** are synergistically formed using various common structural features. As a result, the gate stack **202***a* of the NMOS transistor **280** and the layer stack **202***b* of the PNP L-BJT **240** have one or more corresponding layers having a common physical dimension or material. For example, one or both of the dielectric layer and the conducting layer of the layer stack **202***b* may be formed simultaneously or using the same process recipes, and consequently be formed of the same materials and have the same thicknesses as the corresponding ones of the gate dielectric and the gate of the gate stack **202***a*. Furthermore, in some embodiments, the gate stack **202***a* and the layer

stack **202***b* may be patterned using a mask designed with similar design rules, such that one or more lateral dimensions of the gate stack **202***a* and the layer stack **202***b* may be substantially the same. In addition, the gate stack **202***a* of the MOS **280** transistor and the layer stack **202***b* of the PNP L-BJT **240** have corresponding spacer structures **216***a*, **216***b* formed on sidewalls thereof having a common physical dimension. Similar to the layer stack **202***b*, the spacer structures **216***a*, **216***b* may be formed simultaneously or using the same process recipes, and consequently be formed of the same materials and have the same physical dimensions. Furthermore, the NMOS transistor **280** and the PNP L-BJT **240** have corresponding implanted diffusion regions having a common implanted dopant profile, e.g., as a result of being formed simultaneously or using the same implant masks and/or recipes, and consequently have the same implant profile in one or more directions.

[0134] Advantageously, the lateral arrangement of the emitter region **206**, the base region **201** and the collector region **211** in a direction parallel to a main surface of the common substrate **290** allows for enhanced simultaneous or parallel processing of and/or sharing process recipes between various steps between the MOS transistors **280**, **230** and the L-BJTs **240**, **235**.

[0135] For example, patterning including lithography and etch for defining the gate stack **202***a* of the NMOS transistor **280** and the layer stack **202***b* of the PNP L-BJT **240** can be co-processed, i.e., simultaneously processed. As a result, according to embodiments, the layer stack **202***b* of the PNP L-BJT **240** over a collector region **211** thereof can have a dielectric layer that is co-deposited or co-formed by oxidation with and can have the same thickness as a gate dielectric of the NMOS transistor **280**. Similarly, the layer stack **202***b* of the PNP L-BJT **240** has a conducting layer on a dielectric that is co-deposited with and can have the same thickness as a gate electrode on a gate dielectric of the NMOS transistor **280**. After co-forming the layer stack **202***b* of the PNP L-BJT **240** and the gate stack **202***a* of the NMOS transistor **280**, the layer stack **202***b* of the PNP L-BJT **240** and the gate stack **202***a* of the NMOS transistor **280** can be co-patterned using shared lithography and etch processes. In some cases, the layer stack **202***b* of the PNP L-BJT **240** and the gate stack **202***a* of the NMOS transistor **280** can correspond to a length of a drift region **205** of the BJT and a channel length of the MOS transistor in the first direction, respectively.

[0136] Thus patterned or co-patterned gate stack **202***b* and layer stack **202***b* can be used as hard masks for ion implants. For example, the corresponding regions can be co-implanted using the same energy and/or dose, and can further have substantially the same dopant profile. For example, using the gate stack **202***b* and layer stack **202***b* as patterning layers, which may further include patterning layers remaining thereover, e.g., photoresist or hard masks, lightly doped (LD) source and drain regions of the n-channel NMOS transistor **280** can be co-implanted with the base well **208** of the PNP L-BJT **240**. Similarly, an LD source and drain regions of the p-channel MOS transistor **230** can be co-implanted with a base well of the NPN L-BJT **235**.

[0137] After the LD implants, spacers **216***a*, **216***b*, can be co-formed on sidewalls of the gate stack **202***a* of the NMOS transistor **280** and the layer stack of the PNP L-BJT **240**. As a result, a spacer **216***b* of the PNP L-BJT **240** and a spacer **216***a* of the NMOS transistor **280** can be formed by co-depositing a spacer layer, e.g., a nitride or oxide layer, and co-etched, e.g., anisotropically co-etched to have the same lateral dimension and define one or more implanted diffusion regions for the PNP L-BJT **240** and the NMOS transistor **280** that have the same type of implant and, in some cases, a common implanted dopant profile.

[0138] Using the spacer **216***b* of the PNP L-BJT **240** and the spacer **216***a* of the NMOS transistor **280** that have been co-formed, an emitter region **206** of the PNP L-BJT **240** and source and drain (S/D) regions **207**, **209** of the MOS transistor can be defined by co-implantation. The NMOS transistor **280** is an n-channel MOSFET and PNP L-BJT **240** is a PNP BJT so the S/D regions are 207, 209 and the emitter region **206** can be n-doped, e.g., co-implanted with an n-type dopant. Similarly, the S/D regions MOS transistor **230**, which is an p-channel MOSFET, and the emitter region of the NPN L-BJT **235**, which is an NPN BJT, are p-doped, e.g., co-implanted with a p-type

dopant.
[0139] In addition, prior to forming the gate stacks (e.g., the gate stack **202***a*) and the layer stacks (e.g., the layer stack **202***b*), a common patterning layer can be used to define, by co-implantation processes, the collector regions of the BJTs and the channel regions of the MOS transistors. When the channel region is a p-doped well region (e.g., the channel region **203**) of a n-channel MOS transistor (e.g., the NMOS transistor **280**), it may be co-implanted with a p-type collector region (e.g., the collector region **211**) of a PNP L-BJT (e.g., the PNP L-BJT **240**). Similarly, when the channel region is an n-doped well region of a p-channel MOS transistor (e.g., the PMOS transistor **230**), it may be co-implanted with n-type collector region of a NPN L-BJT (e.g., the NPN L-BJT **235**).
[0140] Further regions of the highly doped (HD) and lightly doped (LD) collector regions of the L-BJTs can be defined by co-implantation with the corresponding HD and LD implants in the S/D regions of the MOS transistors. For a PNP L-BJT (e.g., PNP L-BJT **240**), the p-type collector region (e.g., the collector region **211**) comprises an HD region that is co-implanted with p-doped S/D regions of a p-channel MOS transistor (e.g., the MOS transistor **230**) and the p-type emitter region **206** of the PNP. For an NPN L-BJT (e.g., the NPN L-BJT **235**), the n-type collector region comprises an HD region that is co-implanted with n-doped S/D regions of an n-channel MOS transistor (e.g., NMOS transistor **280**) and an n-type emitter region of the NPN L-BJT **235**).
[0141] For the PNP L-BJT (e.g., the PNP L-BJT **240**), the p-type collector region **211** comprises an LD doped region that is co-implanted with a p-doped LD S/D regions a p-channel MOS transistor (e.g., the MOS transistor **230**) and a p-type base well of an NPN L-BJT (e.g., the NPN L-BJT **235**). Similarly, for the NPN L-BJT (e.g., the NPN L-BJT **235**), the n-type collector region comprises an LD doped region that is co-implanted with a n-doped LD S/D regions of an n-channel MOS transistor (e.g., the NMOS transistor **280**) and a n-type base well (e.g., the base well **208** and the base region **201** therein) of an PNP L-BJT (e.g., the PNP L-BJT **240**).
[0142] In the above, various corresponding structures of CMOS and L-BJT devices have been described as advantageously being adapted for co-fabrication according to embodiments, e.g., simultaneously fabricated. However, embodiments are not so limited, and the corresponding structures can be fabricated sequentially. Even when sequentially fabricated, it will be appreciated that, because of shared design rules, various process recipes, e.g., deposition, etch and implant recipes, can be synergistically used for fabricating the corresponding structures in CMOS and L-BJT devices.
MOS Transistor and L-BJT with Extended Drain and Drift Regions
[0143] As described above the design and structures described above may be used to co-fabricate L-BJTs with MOS transistors (MOSFETs) for a BiCMOS platform. In some cases, these L-BJTs may be low voltage (LV) BJTs having a maximum operating voltages less than 5 Volts. As such, the operating voltage of BiCMOS circuits fabricated based on conventional MOS transistors (e.g., MOSFETs) and the disclosed L-BJTs, may be limited while for some applications MOSFETs and BJTs operating at higher voltages (e.g., larger than 10 Volts, 100 Volts, 200 Volts, or 300 Volts) and co-fabricated on a common substrate may be desired.
[0144] To address these and other needs, a second inventive aspect described herein is directed to elevating the operating voltage of a bipolar junction device (e.g., a lateral BJT) co-fabricated with MOS transistor on a common substrate, e.g., by increasing the length of at least one drift region of the bipolar junction device. Similarly, the operating voltage of the MOS transistor (e.g., a MOSFET) may be elevated to a higher voltage range (e.g., 5-400V) by increasing the length of a channel region of the MOS transistor. In some implementations, the drift region of an L-BJT may be extended along a lateral direction, parallel to the common substrate, from an LD collector region to a base region of the L-BJT Similarly, the channel region of the MOS transistor may be extended along the lateral direction from an LD source region to an LD drain region. In some cases, including an extended gate stack over the channel region of a MOSFET, and/or an extended layer

stack over the drift region of an L-BJT may further increase the operating voltage of a device, by maintaining a magnitude of a lateral component of an E-field constant along the drift or channel region.

[0145] FIG. **3**A schematically illustrates a side cross-sectional view of a high voltage (HV) MOSFET **300** having an extended drain region and an extended gate stack. The extended drain region comprises the channel region **203** and an extended drain region **304***a*. The extended gate stack comprises the gate stack **202***a* and a gate stack extension section **302***a*. Similar to MOSFET **280**, the HV MOSFET **300** includes a source region **207**, and a drain region **309**. In some examples, the drain region **309** of the HV MOSFET **300** includes a highly doped region while the drain region **209** of the MOSFET **280** may include a highly doped and a lightly doped region.

[0146] FIG. **3**B schematically illustrates a side cross-sectional view of a high voltage (HV) L-BJT **350** having an extended drift region and an extended layer stack. The extended drift region comprises the drift region **205** and a drift region extension **304***b*. The extended layer stack comprises the layer stack **202***b* and a layer stack extension section **302***b*. Similar to the PNP L-BJT **240**, the HV L-BJT **350** includes an emitter region **206** and a base region **201** at one end of the extended drift region, and a collector region **311** at the other end of the extended drift region closer to the layer stack extension **302***b*. In some examples, the collector region **311** of the HV L-BJT **350** includes a highly doped region while the collector region **211** of the MOSFET **240** may include a highly doped and a lightly doped region.

[0147] In some implementations, the HV L-BJT **350** is co-fabricated with the MOSFET **300** on a common substrate **290**. Advantageously, the longer drift, channel, layer stack, and gate stacks of the HV MOSFET **300** and the HV BJT **350** make their maximum operating voltage larger than the corresponding MOSFET **280** and the PNP L-BJT **240**. A voltage applied on the HD drain region of the HV MOSFET **300** or the HD collector region of the HV L-BJT **350**, may drop along the extended drain region and drift region, respectively. In some cases, the voltage can drop by at least 50% from the HD drain region of the HV MOSFET **300** and the HD collector region of the HV L-BJT **350** to the source region **209** and base region **201**, respectively.

[0148] As used herein, a maximum operating voltage (also referred to as break down voltage) of a MOS device (e.g., a MOSFET) or a bipolar device (e.g., an L-BJT) can be a voltage above which at least one junction and/or at least one dielectric layer within the device electrically breaks down, e.g., under a reverse bias.

[0149] The HV MOSFET **300** and the HV L-BJT **350** may comprise one or more features described above with respect to the NMOS transistor **280** and the PNP L-BJT **240**. As such, in some examples, one or more regions, and/or layers of the HV MOSFET **300** may be co-fabricated with the corresponding regions, and/or layers of the HV L-BJT **350** and have the same or substantially identical physical dimensions. Additionally, one or both of the extended layer stack of the HV L-BJT **350** and the extended gate stack of the HV MOSFET **300**, may have the same physical dimensions and may be co-fabricated during the same fabrication step(s).

[0150] In some embodiments, at least one structure, one dimension or one doping profile of the L-BJT designs described above, may be different from those of the corresponding feature in a MOS transistor co-fabricated with the L-BJT. As a result, at least one fabrication step of the L-BJT may be a dedicated fabrication step that is not associated with a fabrication of a corresponding feature in the MOS transistor. A dedicated fabrication step may include but it is not limited to forming or doping a region (e.g., diffusing a dopant), etching a structure (e.g., a spacer), disposing a layer, and the like.

Potential Divider

[0151] A third inventive aspect of the disclosed technology is elevating the low voltage BiCMOS platform to a higher voltage node through the use of a high voltage (HV) potential divider. This inventive aspect arises from the inventors' recognition that high voltage devices based on a BCDMOS process platform, e.g., the MOS and bipolar devices having extended drift and channel

regions described above, can be conceptually divided into two regions. In some cases, a first region of the device is designed to operate at a low voltage (e.g., less than 5 Volts) and a second region of the device, which may be physically separated or at least partly isolated from the first region, is designed to provide a voltage drop from a higher voltage (e.g., 5-400 Volts) to a safe voltage level that can be applied on the first region. In some examples, the first region may include a high performance and low voltage channel portion of a MOS device (e.g., a MOSFET), or a high performance and low voltage emitter-base region of a bipolar device (e.g., an L-BJT). The second region may include an extended drift region or extended drain region that translates a high voltage provided to the HD drain region or the HD collector region into a low voltage near the source region or for base region of a MOS transistor or LBJT respectively.

[0152] In recognition of this conceptual divide between low voltage/high performance (5V or less) regions and voltage drop regions of BCDMOS process architectures, inventive aspects include a BCDMOS process architecture that can support a broad range of voltages by physically dividing the a MOS or bipolar device into a first region that supports a high performance at a low voltage and a second region that includes a potential divider (PD) that can be electrically connected or wired in series with any one of the low voltage regions or components to create a high voltage device. Both regions can be fabricated using a low cost and fast cycle time bipolar-CMOS (BiCMOS) core process and platform on the same substrate, examples of which have been described above.

[0153] FIG. **4**A schematically illustrates a side cross-sectional view of the HV MOSFET **300** with an extended drain region. A first region **404** of the HV MOSFET **300** may be a low voltage MOS section comprising the source region **207** and at a least a portion of the gate stack **202***a*. A second region **402** of the HV MOSFET **300** may be a PD section comprising the extended drain region and the drain region **209**. FIG. **4**B schematically illustrates a side cross-sectional view of the lateral bipolar junction transistor (L-BJT) **350** with extended drift region. A first region **454** of the HV L-BJT **350** maybe a low voltage bipolar section comprising the emitter and base regions and at a least a portion of the layer stack. A second region **452** of the HV L-BJT **350** may be a PD section comprising the extended drift region and the collector region.

[0154] While the operating voltage of a MOS or bipolar device can be increased (e.g., above 5 Volts) by increasing the length of a channel or drift regions, applying a high voltage on a region of an integrated device that is physically close to a region designed to handle a lower level of voltage (e.g., the first region **404** or **454**), may lower the reliability of the device. For example, certain parasitic effects may couple a portion of the high voltage to the first region **404** (or first region **454**) of the HV MOSFET **300** (or L-BJT **350**) and cause a junction or dielectric breakdown in the first region **404** (or the first region **454**). Correct

[0155] In some embodiments, physically separating the first regions **404**, **454** (the low voltage sections) from the corresponding second regions **402**, **452** (the potential divider sections) may improve the reliability of the corresponding device, e.g., by reducing the probability of a breakdown caused by parasitic voltage coupling between the low voltage and potential divider sections. Additionally, physically separating the first regions **404**, **454** (the low voltage sections) from the corresponding second regions **402**, **452** (the potential divider sections) may prevent the minority carriers generated through weak impact ionization from attacking the delicate gate oxide. Additionally, physical separation between the low voltage and potential divider sections of MOS and bipolar devices may allow using a potential divider section for coupling multiple devices of the same or different types. For example, a potential divider may receive a high voltage and provide a reduced voltage to two or more devices comprising L-BJTs and MOSFETS.

[0156] In various implementations, physical separation may comprise reducing an/or limiting electric, magnetic, or electromagnetic coupling between the first and the second regions with isolation (herein referred to as isolation). As such, physical separation can include providing a distance and/or an isolating element, layer, or structure between a low voltage section and a PD

section of a device. The distance may include a lateral distance, a vertical distance, or a combination thereof. In some cases, a physical separation that provides sufficient isolation for reducing the risk of breakdown in the low voltage section, may translate to a distance that significantly increases the overall size of the device or the corresponding circuit. As such, in some implementations, one or more low voltage device sections or low voltage substrate regions may be isolated from one or more potential divider sections using one or more isolating elements, layers, or structures.

[0157] In some cases, the PD section may comprise a region of the substrate (herein referred to as PD substrate region) physically separated from a region of the substrate that includes an L-BJT and/or a MOSFET. The L-BJT comprises a collector region electrically connected to a PD substrate region in series and physically separated therefrom by an isolation structure. In some embodiments, the L-BJT further comprises a layer stack comprising a conductive field plate formed over the collector region. In some other embodiments, the collector region and the PD substrate region are electrically connected through one or more metallization levels formed above a major surface of the common semiconductor substrate. In some other embodiments, the PD substrate region is configured to drop >50% of a voltage applied across the BJT and the PD substrate region. According to embodiments, the PD substrate region, which is formed in the same common substrate but physically separated from LV regions including L-BJT and CMOS devices, may be isolated from the LV regions by one or more isolation structures, e.g., dielectric isolation structures including deep or shallow trenches filled with a dielectric material (e.g., an oxide such as silica) and/or junction or well isolation structures.

[0158] Still referring to FIGS. **4**A and **4**B, in some embodiments, the PD section (second regions **402**, **452**) described above, in the context of BJTs or MOSFETs with extended drain and drift regions, may be designed and optimized as a standalone PD device. Connecting a low voltage (LV) device or platform in series with such PD device can scale up the operating voltage of the platform without changing the structure of the device or the platform. In some cases, the PD device may be physically separated from the platform or the LV device similar according to the principles described above with respect to physical separation between the first and second regions of the HV MOSFET **300** and HV BJT **350**, or the PD substrate region from a LV substrate region.

[0159] In some cases, the platform or device may include an integrated circuit (IC) device. According to various aspects, the IC device comprises a metal-oxide-semiconductor (MOS) transistor and a bipolar junction transistor (BJT) formed in a common semiconductor substrate. The PD device can be connected in series with one or more low voltage devices to provide various high voltage MOS and bipolar devices (e.g., HV DMOS, HV BJT, HV MOS, and the like). This gives the BiCMOS core process technology the ability to accommodate a broad range of application voltage nodes with relatively small or no extra cost or redesign of various device structures used for fabricating these devices.

[0160] A fourth inventive aspect is development and optimization of a versatile PD device that can be fabricated using CMOS process. In various implementations The PD device may include an input port, region, or electrode that receives a high voltage (e.g., 5-400 V), an output port, region, or electrode, that outputs a low voltage (e.g., 0-5V) and is configured to be connected to an LV device. As such the PD device is connected in series between a device that provides a high voltage signal and the LV device. In some examples, the PD includes one or more RESURF electrodes or connections configured to be connected to ground potential or the stable low potential of the LV platform or the device to which the PD provides the reduced voltage.

[0161] FIGS. **5**A-**5**C illustrate example embodiments directed to MOS and bipolar junction devices connected to a potential divider (PD) **500**. FIG. **5**A schematically illustrates an isolated PD **500** connected to the NMOS transistor **280**. The RESURF electrodes of the PD **500** are electrically connected to the gate stack of the NMOS transistor **280** and the output port of the PD **500** is electrically connected to the HD drain region of the NMOS transistor **280**.

[0162] FIG. **5**B schematically illustrates an isolated PD **500** connected to a vertical bipolar junction transistor (V-BJT) **506**. The output port of the PD **500** is electrically connected to the collector region of the V-BJT **506**. The RESURF electrodes of the PD **500** are electrically connected to the highest opposing potential, i.e., for an N-type device, a positive voltage would be applied to the PD and the resurf electrodes would be connected to the lowest potential (e.g., ground potential). In some cases, the RESURF electrodes of the PD **500** can be connected to an independent voltage source.
[0163] FIG. **5**C schematically illustrates an isolated PD **500** connected to the lateral bipolar junction transistor (L-BJT) **240**. The RESURF electrodes of the PD **500** are electrically connected to the layer stack of the PNP L-BJT **240** and the output port of the PD **500** is electrically connected to the HD collector region of the PNP L-BJT **240**.
[0164] In various implementations an electrical connection **502** between the RESURF electrodes of the PD **500** and a gate stack, layer stack, of an LV device, and an electrical connection **504** between the output port of the PD **500** and a collector or drain region of the LV device, may comprise a connection through conductive lines in a metallization layer of an IC, which includes the PD **500** and the corresponding LV device. For example, the RESURF electrode and the output port of the PD **500** and the corresponding regions of the LV device can be connected to a common conductive line in a metalized layer above the PD **500** and the LV device, using two or more conductive vias.
[0165] When the LV device is an L-BJT (FIG. **5**C), various synergistic parallel processing with MOS transistors can be performed, including definition of gate stack of the MOS transistor and the layer stack of the BJT, definition of the spacers of the MOS transistor and the BJT and the associated implanted diffusion and definition of various implanted diffusion regions. The details of the synergistic processing have been described above, and not repeated herein for brevity.
[0166] In certain embodiments described herein, the PD device can be a depletion field effect potential divider (DFE-PD) that monotonically (e.g., substantially linearly) drops the voltage from a higher input voltage at a first node (an input node) to a lower voltage at a second node (an output node). Thus, the semiconductor device is suitable for analog signal translation. The PD includes individually doped silicon regions (for example, four regions, or in certain implementations five or more regions) arranged to form a reverse biased depletion junction (first junction) at the input node and a different junction (second junction) at the output node. Charge is coupled from the first junction to the second junction to serve as a potential divider, with the ratio of charge coupling defining the ratio of the voltage scaling. In certain implementations, the full extent of the scaling can range from a direct one-to-one voltage translation to a situation in which the output voltage is independent of the input voltage, and can be fixed to be a substantially constant value.
[0167] Devices employing the above-described voltage reduction schemes can be implemented into various electronic devices. Examples of electronic devices include, but are not limited to, industrial automation/control systems, military and aerospace systems, security and surveillance systems, building technology, instrumentation and measurement systems, power management systems, data acquisition systems, radio frequency communication systems, consumer electronic products, electronic test equipment, communication infrastructure, radar systems, mobile devices (for instance, smartphones or handsets), phased array antenna systems, laptop computers, tablets, and/or wearable electronics.
Vertical Isolation of the Potential Divider
[0168] A fifth inventive aspect includes architectures, designs, and structures for isolating the PD device (e.g., the DFE-PD) or the PD section from the LV devices or LV device sections fed by the PD device. These architectures, designs, and structures can reduce cost, complexity, and/or cycle time for fabricating high voltage BCDMOS platforms, facilitate connecting the PD device to multiple HV devices in the same or different IC layers, and/or enable inclusion of high bandgap materials in the structure of the PD device.
[0169] In some implementations, the PD device or region can be formed in the front end of line

(FEOL) in the same silicon substrate according to some embodiments. In these embodiments, the BiCMOS devices can be isolated from the HV potential divider by an isolation structure such as shallow trench isolation (STI). As shown in FIGS. **5**A-**5**C, such isolation scheme may include lateral isolation of the PD device (or a PD substrate region) from an LV device (or an LV substrate region) using a lateral isolation structure. The lateral isolation structure may comprise a trench filled with a dielectric material (e.g., silicon dioxide). In some cases, the trench can be a deep trench extended from a metalized layer, through which the PD device or section is connected to the LV devices, to a common substrate on which the LV devices are formed. In some cases, the width of the trench may be determined by the magnitude of an input voltage level provided to the PD device. In some examples, multiple lateral isolation structures may be provided at different locations in an IC to isolate the PD device from different lateral directions. In some cases, a lateral distance of the lateral isolation structure from the PD device and the LV device may be determined by the width of a trench and an input voltage level provided to the PD device.

[0170] In some embodiments, for modest voltage ranges (e.g., less than 50V) a junction boundary may be used for laterally isolation the PD device or section from the LV device or section. In some cases, the depletion with of the junction boundary (isolating junction) may be determined based on a magnitude of a voltage drop from an input node of the PD device or region to the LV device or region. In some cases, the depletion width of an isolating junction can be from 10 to 20 microns. When possible, using a junction boundary as an isolation structure (e.g., a lateral isolation structure) may reduce the fabrication cost of the IC. However, given that the depletion width of the junction boundary may scale with the magnitude of the voltage drop, this isolation scheme may consume more substrate space.

[0171] In alternative implementations, the potential divider can be formed in the backend of line (BEOL) above the substrate. In these embodiments, the BiCMOS devices can be vertically isolated from the PD by at least one intermetal or interlayer dielectric (IMD or ILD) layer, thereby obviating the need for lateral isolation at the higher voltage nodes.

[0172] FIG. **6**A schematically illustrates a vertically isolated PD **600** that may be fabricated above a substrate that includes the electronic devices that electrically connected to the PD **600** to receive a reduced voltage. Similar to the PD **500**, the PD **600** includes one or more input electrodes **604**, one or more RESURF electrodes **606**, and one or more output electrodes **608**. A dielectric structure **610** (e.g., an oxide structure), vertically isolates the PD **600** from the LV devices and regions below the dielectric structure **610**. In some cases, the dielectric structure **610** may be the cladding dielectric layer **224** disposed over the substrate **290** of the corresponding IC. FIG. **6**B schematically illustrates a potential divider **612** formed in the backend-of-the-line (BEOL) within the cladding dielectric layer **224**. The PD **612** receives an input voltage (e.g., 5-400V) from an input electrode **604** and outputs a reduced voltage (0-5V) via the output electrode **608**. The output electrode **608** can be connected to one or more input nodes or regions of the BCDMOS devices fabricated on the substrate **290**.

[0173] In some implementations, vertical isolation of the PD **612** may facilitate forming one or more regions of the PD **612** using wide band gap materials. Advantageously a PD that includes a wide band gap material may improve the performance of the PD **612** to provide a better design trade-off for industry leading performance. For example, a PD device that includes a wide band gap material may reduce higher voltage levels (e.g., larger than 400 V) to a voltage level usable by LV devices.

[0174] By employing the low voltage and high performance BiCMOS devices and the PDs according to embodiments, a “superset” process architecture platform according to various embodiments may be realized. The process architecture platform according to embodiments can greatly reduce the number of masks and manufacturing cost, e.g., by as much as about 50%.

Low Voltage, High Performance BiCMOS Process Architecture: Low Voltage-Lateral BJT

[0175] As described above, an inventive aspect of the disclosed technology is directed to a process

architecture that facilitates the construction of a high performance, low cost, low voltage (5V or less), and fast cycle time BiCMOS technology platform using digital cell libraries used for fabricating CMOS devices. In a conventional BiCMOS process, BJTs are fabricated to have a vertical arrangement of emitter, base, and collector regions to allow control over vertical doping profile of each layer and in particular the base length, which in this case is a vertical distance between the junction between the base collector and the junction between the base and the emitter of the BJT. The vertical direction is a direction perpendicular to a main surface of a common substrate on which the BJT and the MOS devices are fabricated. Most fabrication steps required for fabricating a vertical BJT (V-BJT) cannot be synergistically combined with those of the MOS devices and thereby increase cost, complexity, and cycle time of a conventional BiCMOS platform compared to a CMOS platform.

[0176] In some cases, a lateral BJT (L-BJT) design uses a lateral arrangement of the emitter, base, and collector regions co-fabricated with corresponding features of MOS devices using CMOS fabrication techniques, to provide a high-performance bipolar junction device (e.g., a BJT). In some implementations, the disclosed L-BJT designs include regions with similar physical dimensions, dopants, doping profiles, doping regions, spacers, layer stacks, and other features corresponding to the same or similar features in a MOS transistor (e.g., MOSFET), providing maximum synergy between CMOS and L-BJT fabrication processes. As such, cycle time, cost, and complexity of fabricating a BiCMOS platform based on L-BJTs can be significantly reduced with respect to a BiCMOS platform fabricated based on V-BJTs.

[0177] Advantageously, the L-BJT designs described above and with more details below, provide synergy with CMOS fabrication without trading the high performance desired for a BJT on the BiCMOS platform. For example, since the base length of the L-BJT is defined using the spacer structures and the corresponding processing steps tailored and optimized over several decades in the context of MOS fabrication, very thin base regions may be fabricated with high precision to provide high gain. In other words, the structure of the L-BJT can be tailored with high precision based on features and fabrication steps of a MOS transistor, not only to provide synergy between the corresponding fabrication steps, but also to utilize the precision of the MOS fabrication process to improve the performance of BJTs in BiCMOS platforms.

[0178] FIG. **7**A illustrates a cross-sectional view of the PNP L-BJT **240** (previously described in FIG. **2**) and a corresponding schematic dopant concentration distribution **241**. In some implementations, the PNP L-BJT **240** may comprise an emitter region **206**, a base region **201**, a collector region **211**, and a layer stack formed over a portion of the collector region **211**. The emitter region **206** comprises a highly doped (HD) semiconductor material having a first polarity or semiconductor type (e.g., p-type or n-type) and is formed in a lightly doped (LD) base well **208** having a second polarity or semiconductor type opposite to the first polarity or semiconductor type. In some cases, the HD emitter region **206** and the LD base well **208** may comprise the same semiconductor material doped with dopants of opposite types (n-type and p-type). The collector region **211**, may comprise a drift region **205**, an HD collector region **707**, and at least a portion of the LD collector region **710**. In some examples, the collector region **211**, the LD collector region **710** are formed a common well **212**. The HD and LD collector regions **707**, **710**, and the common well **212** may comprise a same type (p-type or n-type) of semiconductor material. In some embodiments, the layer stack may comprise a reduced surface field (RESURF) dielectric layer **717***b* (e.g., an oxide layer such as silica), a RESURF layer **714***b* disposed on the RESURF dielectric layer **717***b*, and a RESURF contact layer **712***b* disposed on the RESURF layer **714***b*. Additionally, the PNP L-BJT **240** may comprise spacers **716***b*, disposed on the sidewalls of the stack layer. The RESURF layer **714***b*, the RESURF contact layer **712***b*, and the base and collector spacers **216***b*, may comprise different types of materials. The layer stack may be disposed on of the drift region **205** of the BJT **240**.

[0179] As described above, the layer stack may be configured as a RESURF layer stack to maintain

a magnitude of the lateral electric field component along the drift region **205** constant, and thereby increase the operating voltage of the PNP L-BJT **240**. Equivalently, the layer stack may allow increasing a doping concentration of the drift region without reducing the operating voltage of the PNP L-BJT **240**. In some cases, the RESURF layer **714***b* can be maintained at a RESURF potential by connecting the contact layer **714***b* to voltage source providing the RESURF potential. The RESURF potential can be a potential less than a potential of the HD collector region **707** (also referred to as collector potential). In some cases, the RESURF potential can be close or substantially equal to a potential of the emitter region **206**. In some cases, the RESURF potential is substantially equal to the ground potential. In some cases, the operating voltage of the L-BJT may increase proportional to a difference between the RESURF potential and the collector potential. Equivalently, for a given operating voltage, the doping concentration of the base region **201** and/or the drift region **205** may be increased proportional to a difference between the RESURF potential and the collector potential.

[0180] Including the layer stack in the structure of the L-BJT provides at least a three-fold advantage over conventional BJTs (e.g., V-BJTs) used in BiCMOS platforms, including: (1) enabling co-fabrication of the emitter region **206** of the PNP L-BJT **240** with the HD source region **720** of the NMOS transistor **280**, and simultaneously forming the base region **201**; (2) Increasing the operating voltage of the L-BJT or increasing the doping concentration of the base region **201** and/or drift region **205**; and (3) fabricating high gain L-BJT having precisely defined short base length.

[0181] In some examples, the entire structure of an L-BJT may be formed in a common well. In some other examples, such as PNP L-BJT **240**, an L-BJT may be partially formed in a common well and a second region (e.g., a second well) comprising a semiconductor having opposite dopant types, and/or an opposite polarity compared to the common well. In such examples, the common well and the second region may have an interface under the base well **208** such that a first portion of the base well **208** shares an interface with the common well **212** and a second portion of the base well **208** shares an interface with the second well. In some cases, an electrical connection may be provided to the LD base region above the second well. In the example shown, the PNP L-BJT **240** is a PNP BJT having a p-type HD emitter region (P.sup.++) **206** formed in an n-type LD base well **208**, and a p-type collector region comprising a p-type well **204** comprising HD and LD collector regions **207**, **210**, formed in the p-type well **204**. As shown, in this example, the base LD region **208** is partially formed in the p-well (the common well) and an n-type well **202** that shares an interface with the p-well **204** under the LD base region.

[0182] The schematic dopant concentration distribution **241** shows relative doping levels in the PNP L-BJT **240** along the lateral direction (e.g., y-axis). A dopant concentration (D.sub.E) in the emitter region can be larger than a dopant concentration (D.sub.B) in the base region. A dopant concentration (D.sub.CHD) in the HD collector region can be larger than a dopant concentration in the LD collector region (D.sub.CLD). A dopant concentration (DDR) in the drift region can be smaller than D.sub.B and D.sub.CLD. In some examples, D.sub.B and D.sub.CLD can be different or substantially equal. In some examples, D.sub.E and D.sub.CHD can be different or substantially equal. In some cases, DDR can be from 5×10.sup.15 cm.sup.−3 to 5×10.sup.16 cm.sup.−3. D.sub.B and can be from 10.sup.16 cm.sup.−3 to 10.sup.18 cm.sup.−3, and D.sub.E and D.sub.CHD can be larger than 10.sup.18 cm.sup.−3.

[0183] FIG. **7**B schematically illustrates a side cross-sectional view of a NMOS transistor **280** and the corresponding dopant concentration distribution. In some embodiments, the NMOS transistor **280** can be a field effect (FET) transistor comprising a drain region, a source region, and a gate stack formed over a channel region **203** between the drain region and the source region. The source region may include a highly doped (HD) source region **220** formed in a common well **212**. Similarly, the drain region of the MOSFET **280** may include a highly doped (HD) drain region **220** formed in a lightly doped drain region (LD) region **209**, where the HD drain (or source) and LD

drain (or source) regions comprise a semiconductor of the same type or polarity (n-type or p-type). The gate stack may comprise a gate dielectric layer **217***a* (e.g., an oxide layer), a gate layer **214***a* disposed on the gate dielectric layer **217***a*, and a gate contact layer **212***a* disposed on the gate layer **214***a*. Additionally, the NMOS transistor **280** may comprise gate spacers **216***a* disposed on the side walls of the gate stack. The gate layer **214***a*, the gate contact layer **212***a*, and the gate spacers **216***a*, each may comprise a different type of material.

[0184] In some cases, the HD and LD regions of the MOSFET **280** may comprise the same semiconductor materials (e.g., silicon) doped with the same dopant. The source and drain regions are formed in a well comprising a semiconductor doped with a dopant type opposite to that of the source and drain regions. In the example shown, the MOSFET **280** is an n-channel MOSFET having n-type drain and source regions formed in a p-type well, each comprising a n-type HD region (N.sup.++) formed in an n-type LD region.

[0185] The dopant concentration distribution **281** shows relative doping concentration in the MOSFET **280** along the lateral direction (e.g., y-axis). A dopant concentration (D.sub.SHD) in the HD source region can be larger than a dopant concentration (D.sub.SLD) in the LD source region. Similarly, the dopant concentration (D.sub.DHD) in the HD drain region can be larger than a dopant concentration (D.sub.DLD) in the LD drain region. A dopant concentration (D.sub.CH) in the channel region can be smaller than D.sub.DLD and D.sub.SLD. In some examples, D.sub.SHD and D.sub.DHD can be different or substantially equal. In some examples, D.sub.SLD and D.sub.DLD can be different or substantially equal. In some cases, D.sub.CH can be from 5×10.sup.15 cm.sup.−3 to 5×10.sup.16 cm.sup.−3, D.sub.SLD and D.sub.DLD can be from 10.sup.16 cm.sup.−3 to 10.sup.18 cm.sup.−3, and D.sub.SHD and D.sub.DHD can be larger than 10.sup.18 cm.sup.−3.

[0186] In some implementations, with the exception of the layer stack and the gate stack, all the regions and wells of the PNP L-BJT **240** and the NMOS transistor **280** and the substrate **290** may comprise single crystalline silicon. The isolating dielectric layers **218**, the gate dielectric layer, and the RESURF dielectric layer may comprise a dielectric layer (e.g., an oxide such as thermally grown or deposited silicon dioxide or other suitable dielectric layer such as a high K dielectric layer), the gate and RESURF layers may comprise polysilicon or a metal, and the gate and RESURF contact layers may comprise a silicide. In some implementations, isolating dielectric layers **218**, may comprise oxide layers (e.g., silica layer) thermally grown on the surface of the substrate **290**. In some other implementations, isolating dielectric layers **218**, may comprise layers or regions (e.g., silica layers) fabricated by forming trenches in the substrate **290** and depositing the oxide material in the trench.

[0187] In various implementations, a highly doped (HD) region may have a doping concentration (concentration) from 10.sup.18 cm.sup.−3 to 10.sup.20 cm.sup.−3, a lightly doped (LD) region may have a doping concentration (concentration) from 10.sup.16 cm.sup.−3 to 10.sup.18 cm.sup.−3, and a very lightly doped (VLD) region may have a doping concentration less than 10.sup.15 cm.sup.−3.

[0188] In some cases, the depth of the LD source region **709** and/or the base well **208** along a vertical direction (e.g., along z-axis) can be from 0.2 microns to 1.0 microns.

[0189] In some cases, the width of the LD source region **709** and/or the base well **208** along a lateral direction (e.g., along y-axis) can be from 0.18 microns to 2.0 microns.

[0190] In some cases, the depth of the LD drain region **711** and/or the LD collector region **710** along the vertical direction can be from 0.2 microns to 1.0 microns.

[0191] In some cases, the width of the LD drain region **711** and/or the LD collector region **710** along a lateral direction (e.g., along y-axis) can be from 0.18 microns to 2.0 microns.

[0192] In some cases, the depth of the HD source well **208** HD and/or the emitter region **206** along a vertical direction (e.g., along z-axis) can be from 0.1 microns to 0.2 microns.

[0193] In some cases, the width of the HD source well **208** and/or the HD emitter region **206** along

a lateral direction (e.g., along y-axis) can be from 0.18 microns to 1.0 microns.
[0194] In some cases, the depth of the HD drain region **721** and/or the HD collector region **707** along the vertical direction can be from 0.1 microns to 0.2 microns.
[0195] In some cases, the width of the HD drain region **721** and/or the HD collector region **707** along a lateral direction (e.g., along y-axis) can be from 0.18 microns to 1.0 microns.
[0196] In some cases, a length of the channel region **203** and/or the drift region **205** along the lateral direction can be from 0.18 microns to 0.6 microns.
[0197] In some cases, a length of the RESURF layer **714***b* along the lateral direction (e.g., along y-axis) can be substantially equal to a length of the drift region along the lateral direction.
[0198] In some cases, the thickness of the gate layer **714***a*, and/or the RESURF layer **714***b* along a vertical direction (e.g., along z-axis) can be from 0.1 microns to 0.3 microns.
[0199] In some cases, the thickness of the gate contact layer **712***a*, and/or the RESURF layer **712***b* along a vertical direction (e.g., along z-axis) can be from 0.02 microns to 0.05 microns.
[0200] In some cases, the thickness of the gate dielectric layer **717***a*, and/or the RESURF dielectric layer **774***b* along a vertical direction (e.g., along z-axis) can be from 0.01 microns to 0.02 microns.
[0201] In some cases, a width of a bottom portion the spacers **216***a* and **216***b* (e.g., at the interface between the spaces **216***a*, **216***b* and the dielectric layers **217***a*, **217***b*, respectively), along a lateral direction can be from 0.05 microns to 0.15 microns.
[0202] In some cases, the length of the base region **201** (base length, L.sub.B) extended from the drift region **205** to the HD emitter region **206** along a lateral direction (e.g., along y-axis), can be from 0.03 microns to 0.05 microns, from 0.05 microns to 0.07 microns, from 0.07 microns to 0.1 microns, from 0.1 microns to 0.13 microns, from 0.13 microns to 0.15 microns, from 0.15 microns to 0.17 microns, from 0.17 microns to 0.2 microns, or any value in range formed by these values.
[0203] In some implementations, the length of the base region **204** is substantially equal to the width of the bottom portion of the spacers **216***a* and **216***b*.
[0204] Still referring to FIGS. **7**A and **7**B, as the described above, the PNP L-BJT **240** and the NMOS transistor **280** can be fabricated on a common substrate by fabricating the regions and structures of the NMOS transistor **280** and the corresponding regions and structures of the PNP L-BJT **240**, during same fabrication steps or same process recipes at different steps. For example, the gate stack and the spacers of one or more (MOS transistors) can be co-fabricated with the RESURF stack and the spacers **216***b* of the PNP L-BJT **240**. Subsequently, the emitter region **206** of the PNP L-BJT **240** and the HD source regions of one or more a p-channel MOS transistors, which may be structurally identical to the n-channel NMOS transistor **280**, can be co-fabricated. Advantageously, the latter fabrication step simultaneously forms of the base region **201** and the emitter region **206** of the PNP L-BJT **240**.
[0205] In some examples, the gate stack of the NMOS transistor **280** and the layer stack of the PNP L-BJT **240** have at least one common physical dimension, as a result of being co-fabricated or using the same fabrication recipes. For example, the gate layer **714***a* may have at least one physical dimension in common with the RESURF layer **714***b*, and/or the gate contact layer **712***a* may have at least one physical dimension in common with the RESURF contact layer **712***b*. Similarly, the spacers **716***b* may have at least one physical dimension in common with the gate spacers **216***a*. Additionally, in some examples, the spacers may comprise the same material, the RESURF and the gate layers may comprise the same material, and the RESURF and the gate contact layers may comprise the same material.
[0206] In some cases, the LD base well **208** and the LD source region **709** may have at least one common dimension, the HD emitter region **206** and the HD drain region **721** may have at least one common dimension, and the HD source region **720** and the HD emitter region **206** may have at least one common dimension. In some examples, the LD regions and/or HD regions may comprise the same material with the same or different polarities.
[0207] In some embodiments, at least the LD collector region of an L-BJT, the LD drain region,

and the LD source regions of a MOSFET may be formed in a single well (e.g., a common well). In some such cases, the HD and LD drain and source regions of the MOSFET may have a polarity and/or comprise a dopant type, different from those of the HD and LD collector regions and the HD emitter region of the L-BJT.

[0208] In some cases, the spacers **216***b*, and the spacers **216***a* may have substantially identical dimensions (e.g., within the tolerance of a corresponding fabrication process), the RESURF layer **714***b* and the gate layer **714***a* may have substantially identical dimensions, and/or the RESURF contact layer **712***b* and the gate contact layer **712***a* may have substantially identical dimensions.

[0209] In some cases, the LD base well **208** and the LD source region **709** may have substantially identical dimensions, and/or the HD emitter region **206** and the HD drain region **721** may have substantially identical dimensions.

[0210] In various implementations, the gate layer **714***a*, the RESURF layer **714***b*, the gate layer contact **712***a*, and the RESURF contact layer **714***b* may comprise one or more materials having conductivities larger than 10 Ω/sq, larger than 30 Ω/sq, larger than 50 Ω/sq, or larger than 70 Ω/sq. In some cases, the gate layer **714***a*, the RESURF layer **714***b*, the gate layer contact **712***a*, or the RESURF contact layer **714***b* may comprise doped polysilicon or silicide. The spacers may comprise a dielectric material (e.g., silica).

[0211] In various implementations, the NMOS transistor **280** and the PNP L-BJT **240** may be laterally extended between two isolating dielectric layers **218** (e.g., silica layers) grown or disposed on the substrate **290**.

[0212] In some implementations, and the corresponding features of the MOSFET **280** and the PNP L-BJT **240** that have common physical dimensions may be co-fabricated during the same fabrication step(s) or using the same process recipe. As described with respect to FIG. **2**, the HD emitter region **206**, LD base well **208**, the HD collector region **707** and LD **210** regions, the spacer **216***b*, the oxide layer **217***b*, the RESURF layer **214***b*, RESURF contact layer **212***b* of the BJT **240** are at least structurally similar to the HD source region **220**, LD source region **209***a*, the drain HD **221** and LD **209***b* regions, the gate spacers **216***a*, the oxide layer **217**, the GATE layer **214***a*, GATE contact layer **212***a*, respectively. However, unlike the HD **220** and LD source **209***a* source regions of the MOSFET **280**, the HD emitter region **206** and the LD base well **208** are not of the same type. Despite this minor difference, these common features can be synergistically formed using same processing steps on a single substrate. In some cases, one or more regions or layers of the PNP L-BJT **240** and NMOS transistor **280** may have common physical dimensions, common doping profiles, or common material layers. For example, the layer stack **202***b* (the RESURF layer **214***b* and the RESURF contact **212***b*) of the PNP L-BJT **240**, the layer stack of the NPN L-BJT **235**, the gate stack **202***a* (the gate layer **214***a* and the gate contact layer **212***a*) of the NMOS transistor **280**, and the gate stack of the PMOS transistor **230** may have one or more common physical dimensions including the thickness and/or comprise layers having a common material. Furthermore, the HD and LD collector regions of the NPN L-BJT **235** may have corresponding implanted diffusion regions having common implanted regions with the HD and LD drain regions **721**, **720**, and **709**, **711** of the NMOS transistor **280**.

[0213] In some implementations, D.sub.SLD and D.sub.B can be substantially equal, D.sub.DLD and D.sub.CLD can be substantially equal, D.sub.SHD and D.sub.B can be substantially equal, D.sub.DHD and D.sub.CHD can be substantially equal, and/or D.sub.CH and DDR can be substantially equal. In some cases, DDR for PNP L-BJT **240** can be larger than D.sub.CH for NMOS transistor **280**.

[0214] FIG. **7**C schematically illustrates a side cross-sectional view of another embodiment of an L-BJT **730**. In some cases, an upper level for the operating voltages of L-BJT **730** can be larger to that of the LBT **240**. Similar to the PNP L-BJT **240**, the L-BJT **730** comprises laterally arranged emitter-base and base-collector junctions and may operate mainly based on carrier transport in a lateral direction parallel to a main surface of a substrate on which the L-BJT **730** is fabricated on.

However, the L-BJT **730** may not have a LD collector region and may include a thick RESURF dielectric layer **734***b* in addition to the RESURF dielectric layer **717***b*. The L-BJT **730** may comprise one or more features described above with respect to the PNP L-BJT **240**. The L-BJT **730** may include an HD emitter region **206** formed in an LD base region. The collector region **736** of the L-BJT **730** is a portion of the common well **212** that supports bipolar carrier transport to and from the base region **201** and may include an HD collector region **707**. In some cases, a drift region **705** of the L-BJT can have length extended in the lateral direction (y-axis) from the HD collector region **707** to the base region **201**. The RESURF dielectric layer of the L-BJT **730** may comprise a thin RESURF dielectric layer **734***a* and a thick RESURF dielectric layer **734***b*. Accordingly, a first portion of a RESURF layer **732***a* of the L-BJT **730** may disposed on the thin RESURF dielectric layer **734***a* and a second portion of a RESURF layer **732***a* may disposed on the thick RESURF dielectric layer **734***b*. In some cases, the RESURF layer of the L-BJT **730** can be longer than that of the L-BJT **240**. A space layer **216** may be disposed on a sidewall of the RESURF layer **732***a* and on the thin dielectric layer **734***a*. Similar to formation of the base region **201** of the PNP L-BJT **240**, the base region **201** of the L-BJT **730** may be formed simultaneously with formation of the HD emitter region **206** and using the spacer **216***b*. In some cases, the length of the drift region of the L-BJT **730** can be substantially equal to that of the PNP L-BJT **240**. In some cases, the length of the drift region of the L-BJT **730** can be larger than that of the PNP L-BJT **240**. In some cases, the longer length of the drift region **705** and/or the presence of the thick RESURF dielectric layer **734***b*, may increase an upper limit for the operating voltage of the L-BJT **730** compared to that of the PNP L-BJT **240**. In some cases, extending the length of the drift region **705** may significantly increase the upper limit for the operating voltage of the L-BJT **730**. Examples of L-BJTs having long drift regions, also referred to as L-BJTs with extended drift regions, are discussed below.

[0215] Similar to the PNP L-BJT **240**, in some embodiments, the base well **208** of the L-BJT **730** may be partially formed in the common well **212** and a second region **214**. In some cases, an interface between the collector region **212** and the second region **214** can be aligned with the emitter-base junction of the L-BJT **730**. In some examples, the entire structure of an L-BJT **730** may be formed in the common well **212**.

[0216] In some cases, the L-BJT **730** can be co-fabricated at least partially with MOS transistors similar to the MOS transistor **240**. In some examples, the L-BJT **730** can be co-fabricated with a MOS transistor (e.g., an LDMOS) having a structure similar to the L-BJT **730**. FIG. **7**D schematically illustrates a side cross-sectional view of an LDMOS transistor. The LDMOS transistor **740** comprises an LD source region **709** formed in the common well **212**, an HD source region **720** formed in the LD source region **709**, and an HD drain region formed in the common well **212**. The gate dielectric layer of the L-BJT **730** may comprise a thin gate layer **734***c* and a thick gate dielectric layer **734***d*. Accordingly, a first portion of a gate RESURF layer **732***b* of the MOS transistor **740** may disposed on the thin dielectric layer **734***c* and a second portion of the gate layer **732***b* may disposed on the thick gate dielectric layer **734***d*. The LD base region **208**, the thin RESURF dielectric layer **734***a*, the thick RESURF dielectric layer **734** *b*, the RESURF layer **732***a*, and the HD collector region **707** of the L-BJT **730** may be co-fabricated with the corresponding layers and regions of the MOS transistor to **740** and may comprise substantially identical physical dimensions with those layers and regions.

[0217] The dopant concentration distribution **231** shows relative doping levels in the L-BJT **730** along the lateral direction (e.g., y-axis). A dopant concentration (D.sub.E) in the emitter region can be larger than a dopant concentration (D.sub.B) in the base region. A dopant concentration (DDR) in the drift region can be smaller than D.sub.B and D.sub.CHD. In some cases, the relative doping levels in the LDMOS **740** along the lateral direction can be similar to th3 of the L-BJT **730**. In some cases, DDR for L-BJT **730** can be larger than D.sub.CH for MOSFET **740**.

[0218] The base well **208** of the PNP L-BJT **240** or L-BJT **730** may include one or more HD base regions having the same polarity or semiconductor type as the base well **208**. The HD base regions

may be used to provide electrical connection to the base well **208** and the base region **201**. In some embodiments, the base regions may be aligned with the HD emitter region along a lateral direction (e.g., along x-axis) perpendicular to the lateral direction along which the emitter-base and base-collector junctions are aligned (e.g., y-axis). In some other embodiments, a base region may be aligned with the HD emitter region along a lateral direction (e.g., along y-axis) parallel to the lateral direction along which the emitter-base and base-collector junctions are aligned.

[0219] In some cases, forming the base region **208** partially in the common well **212** and a second region (e.g., a second well) with opposite polarity and aligning the interface between the collector region **212** and the second region **214** with the emitter-base junction of the L-BJT **730** or L-BJT-**240**, may improve the performance of the BJT.

[0220] With reference to FIGS. **2** and **7**A-**7**D, in some embodiments, a length of the layer stack **202***b* along a lateral direction (e.g., along y-axis) can be longer than a length of gate stack **202***a* along the lateral direction. In some embodiments, a length of the HD collector region **707** along a lateral direction (e.g., along y-axis) can be smaller than a length of the HD drain region of the MOS transistor **230** along the lateral direction.

[0221] FIG. **8**A shows a three-dimensional (3D) cross-sectional view of an example L-BJT **800** having an HD base region **802***a* disposed in the base well **208** in a corner region between the HD emitter region **206** and the spacer **216***b* disposed on the side wall of the layer stack **714***b*. FIG. **8**B shows a top two-dimensional (2D) cross-sectional view of the L-BJT **800** in a plane **810** parallel to and above the top surface of the substrate **290**. The base region **802***a* and another base region **802***b* are disposed in two corner regions between the HD emitter region **206** and the spacers **216***b*. The base region **802***a*, HD emitter region **206** and the base region **802***b* are disposed in in the vicinity of the RESURF layer **714***b* and are aligned in a lateral direction along x-axis.

[0222] FIG. **8**C shows a 2D cross-sectional view of another example L-BJT **804** having an HD base region **806** disposed in the base well **208** near an edge of the HD emitter region **206** opposite to another edge near the spacers **216***b* disposed on the side walls of the RESURF layer **714***b* and RESURF dielectric layer **717***b*. The HD base region **806** and the HD emitter region **206** are separated by a gap having a width along the lateral direction from 0.1 to 1 micron. The HD base region **806** has the same polarity as the base well **208**, but it has a higher doping concentration. In some examples, the doping concentration of the HD base region **806** can be larger than 10.sup.20 cm.sup.−3. FIG. **8**D shows a top two-dimensional (2D) view of the L-BJT **804**. The base region **806**, the HD emitter region **206** are aligned in a lateral direction along y-axis.

[0223] In some cases, the base well **208** of L-BJT **804** may be partially disposed in the common well **212** and a second region (e.g., a second well) **214** having an opposite polarity compared to the common well **212**. The HD emitter region **206**, the HD collector region **707**, and the common well **212** (e.g., a well shared with a MOS transistor) have the same polarity that is opposite to a polarity of the base well **208** and the HD base region **806**.

[0224] While the PNP L-BJT **240** or L-BJT **804** can be co-fabricated with a MOS device on a common BiCMOS platform, in some embodiments, at least one feature, structure, doping profile of an L-BJT (e.g., the PNP L-BJT **240** and/or L-BJT **804**) co-fabricated with the corresponding feature, structure, doping profile of one or more MOS devices (e.g., MOSFET **280** and/or MOSFET **230**), may be purposefully adjusted, designed, or tailored to enhance the performance of the L-BJT. In some of such embodiments, such design, adjustment, or tailoring may result in sub-optimal performance of the co-fabricated MOS devices. However, the sub-optimal performance may be in an acceptable range for an IC device and the corresponding application. In some examples, purposeful adjustment of a feature, structure, or doping profile of an L-BJT may take into account its impact on the performance of the co-fabricated MOS devices and maintain it in an acceptable range for an IC device and the corresponding application.

[0225] In some implementations, a change made to a fabrication step of an L-BJT with respect to the corresponding fabrication step in a MOS transistor, may result in significant change in the

performance of the co-fabricated MOS transistor, e.g., degrading its performance below an acceptable or threshold level. In some such implementations, at least one fabrication step of the an L-BJT may be a dedicated fabrication step that is not associated with a fabrication of a corresponding feature in the MOS transistors on the same substrate. A dedicated fabrication step may include but it is not limited to forming or doping a region (e.g., diffusing a dopant), etching a structure (e.g., a spacer), disposing a layer, and the like.

[0226] In some cases, the doping step of the base well **208** may of the PNP L-BJT **240** (a PNP BJT) can be a dedicated fabrication step. In some such cases, a doping profile of the base well **208** can be different from that of a corresponding drain and source regions **209**, **207**, of the MOSFET **280**. In some examples, the location of the peak doping concentration of the doping profile of the base well **208** along the vertical direction (e.g., z-axis) can be at or near the lateral emitter-base junction.

[0227] In some cases, the spacers **216***b* of the PNP L-BJT **240** may be fabricated (e.g., etched) using a dedicated fabrication process independent of a process used to fabricate the spacers **216***a* of the NMOS transistor **280**. FIG. **9**A illustrates a cross-sectional view of an L-BJT **900** having a spacer **901** fabricated using a dedicated process. For example, a top width, a base width, or an average width of the spacer **901** of the L-BJT **900** may be smaller than those of a MOS transistor fabricated in the same common well **212** and/or the same substrate. The base width of the spacer **909** may be a length of a base of the spacer **901**. The base of the spacer **901** may comprise a portion of the spacer **901** at interface between the spacer **901** and the dielectric layer **717***b*. Advantageously, fabricating the spacer **901** using a dedicated fabrication process may allow forming a thin base region having a base length (L.sub.B) less than 0.01 μm, less than 0.05 μm, less than 0.1 μm, or less than 0.15 μm.

[0228] In some cases, the emitter region **206** of an L-BJT (e.g., the PNP L-BJT **240**) may fabricated using a dedicated fabrication process independent of a process used to fabricate the HD drain or source regions of a MOS transistor on the same substrate (e.g., the MOSFET **230**). FIG. **9**B illustrates a cross-sectional view of an L-BJT **902** having an elongated emitter region **907** fabricated using a dedicated process. For example, a length of the emitter region **907** along the lateral direction (e.g., along y-axis) may be larger than those of HD drain and HD source regions of a MOS transistor fabricated on the same substrate. Advantageously, an L-BJT having an elongated emitter region **907** may have a lower base current and higher gain compared to an L-BJT having an emitter length limited by the lengths of the HD drain and HD source regions of a co-fabricated MOS device. Correct In some examples, a length of the base well **912** of the L-BJT **902** may be longer than the LD drain and LD source regions of the MOS transistor fabricated on the same substrate to accommodate for the elongated emitter. As such both the elongated emitter region **907** and the elongated base well **912** of the L-BJT **902** may be fabricated using a dedicated fabrication process or step. In some examples, the length of an elongated emitter region can be from 0.18 to 0.6 microns. In some examples, the length of an elongated base well can be from 0.18 to 1.0 microns.

[0229] In some cases, the emitter region of an L-BJT (e.g., the PNP L-BJT **240**) may be extended in a vertical direction (e.g., along z-axis) to increase the gain of the L-BJT. In such cases, a dedicated fabrication step may be used to fabricate a vertical emitter section on the HD emitter region of the L-BJT. FIG. **9**C illustrates a cross-sectional view of a L-BJT **904** having a vertical emitter section **903**. In some cases, the vertical emitter section **903** may be fabricated using a dedicated fabrication process. The vertical emitter section **903** may comprise polysilicon. In some cases, the vertical emitter section **903** may be disposed on the elongated emitter region **907** of the L-BJT **902**. FIG. **9**D illustrates a cross-sectional view of a L-BJT **906** having an elongated emitter region **907**, and elongated base well **912**, and a vertical emitter section **903**.

[0230] In some embodiments, a dielectric layer **905** may be formed between the emitter region **206** and the vertical emitter section **903**. The dielectric layer **905** (also referred to as interfacial dielectric layer) may be naturally formed during fabrication of the vertical emitter section **903**,

fabricated using a separate process, or a combination of both. In either case, the thickness of the dielectric layer (along the vertical direction) may be precisely controlled. In some examples, the thickness of the interfacial dielectric layer may be from 1 μm to 200 μm. In some cases, the thickness of the dielectric layer **905** may be less than a threshold limit to allow carrier transport between the emitter region **206** and the vertical emitter section **903** via quantum tunneling. In some cases, the dielectric layer **905** may comprise silicon dioxide.

[0231] In various embodiments, the vertical emitter section **903** and the corresponding dielectric layer **905** at the base of the vertical emitter section **903**, may be fabricated using a dedicated process.

[0232] In some cases, an L-BJT (e.g., the PNP L-BJT **240**) can be vertically isolated from a lower region of the substrate (e.g., substrate **290**) below the base well (e.g., base well **206**) and/or the LD collector region of the L-BJT (e.g., LD collector region **710**). In some such cases, a buried dielectric layer (e.g., a buried oxide layer) may vertically isolate the L-BJT from the bulk substrate. Such L-BJT may be fabricated, e.g., in a silicon0on-insulator (SOI) substrate. In some cases, the combination of the isolating layers formed on the surface of the substrate (e.g., the isolation layer **218**) and the vertical isolation layer may fully isolate the L-BJT. FIG. **9**E illustrates a cross-sectional view of a fully isolated L-BJT **908** that is laterally isolated by the isolation layers **218** and vertically isolated by the buried dielectric layer **909**. In some examples, the buried dielectric layer **909** may be in contact with the dielectric layers **218**. In some examples, a vertical gap or distance (e.g., along z-axis) between a bottom surface of the dielectric layer **218** and a top surface of the buried dielectric layer **909** can be less than 150 nm, less than 100 nm, or less than 50 nm.

[0233] In some embodiments, the base wells **208**, **912** of the L-BJT designs described above with respect to FIGS. **9**A-**9**F may be partially formed in the common well **212** and a second region (e.g., a second well) comprising a semiconductor having opposite dopant types, and/or an opposite polarity compared to the common well **212**. In such examples, the common well **212** and the second region **214** may have a vertical interface **725** (shown as a dashed line) underneath the base well **208**, **912**. In some cases, the vertical interface **725** can be aligned with the vertical emitter-base junction of the L-BJT.

[0234] In some implementations, a base region of an L-BJT may be formed and the corresponding base length may be precisely defined by thermal diffusion of a dopants from base well under the RESURF layer. In these implementations, the base width of a spacer used to form the emitter region of the L-BJT is reduced to allow the diffusion of the dopants to a region of the substrate below the RESURF layer. FIG. **9**F illustrates a cross-sectional view of the L-BJT **910** having thermally diffused base region **911** formed by thermally diffusing the dopants from the base well **208** laterally (e.g., along y-axis) underneath the RESURF layer **714***b*. In this case, the base length L.sub.B is precisely defined by controlling the temperature of the sample after formation of the base well **208**. The base width if the spacer **901** is reduced to bring the emitter region **206** closer to the edge of the RESURF later **714***b* to allow the dopants to thermally defuse from the base well **208** under the RESURF layer **714***b*. Is some cases, the fabrication of the spacer **901** and the thermal diffusion of the dopants may be performed as dedicated processes during the fabrication of the L-BJT **910** on a BiCMOS platform comprising the L-BJT **910** and one or more MOS transistors on a common substrate.

[0235] FIGS. **10**A-**10**D schematically illustrate cross-sectional views of intermediate structures at some of the steps in the fabrication process of an L-BJT according to embodiments. FIG. **10**A shows a cross-sectional view of a partially fabricated L-BJT structure during formation of the LD collector region **710**. In some cases, the isolating oxide layers **218**, the RESURF oxide layer **717***b*, the RESURF contact layer **712***b*, and the RESURF layer **714***b*, may have been fabricated using standard CMOS fabrication processes. In some examples, these features may have been co-fabricated with the corresponding features of one or more MOS transistors.

[0236] The fabrication step shown in FIG. **10**A may comprise depositing a patterning layer such as

a photoresist layer and lithographically patterning the photoresist layer to generate a patterned photoresist layer **1002** covering portions of the isolating dielectric layers **218** and the RESURF contact layer **712***b* leaving an edge of the layer stack near the collector region uncovered. After patterning the photoresist layer, the LD collector region may be formed in the common well **212**, e.g., by implanting an n-type dopant (for an NPN L-BJT) or a p-type (e.g., for PNP L-BJT). The dopant selectively penetrate to a region of the common well **212** covered by the unprotected portion of the RESURF oxide layer **717***b* and form the LD collector region **710**.

[0237] A length or width of the collector region **710** along a lateral direction may be determined by a length or width of the unprotected portion of the RESURF oxide layer **717***b*. A depth of the collector region **710** along a vertical direction (perpendicular to a main surface of the substrate) may be determined by the energy of the implanted dopant and a thickness of the RESURF oxide layer **717***b* along the vertical direction.

[0238] The fabrication step shown in FIG. **10**B may comprise removing the patterned photoresist **1002** and depositing a second patterning layer such as a second photoresist layer and lithographically patterning the second photoresist layer to generate a second patterned photoresist layer **1004** covering the portions of the isolating dielectric layers **218** and the RESURF contact layer **712***b* leaving an edge of the layer stack near the emitter/base region uncovered. After patterning the second photoresist layer, the LD base well **208** may be formed in the common well **212**, e.g., by implanting a p-type dopant (for an NPN L-BJT) or an n-type (e.g., for PNP L-BJT). The dopants selectively penetrate to a region of the common well **212** covered by the unprotected portion of the RESURF oxide layer **717***b* and form the base well **208**. A length or width of the base well **208** along a lateral direction may be determined by a length or width of the unprotected portion of the RESURF oxide layer **717***b*. A depth of the base well **208** along a vertical direction (perpendicular to a main surface of the substrate) may be determined by the energy of the implanted dopant and a thickness of the RESURF oxide layer **717***b* along the vertical direction.

[0239] The fabrication step shown in FIG. **10**C may comprise removing the patterned photoresist **1004** and depositing a dielectric layer **1006** covering all regions of the L-BJT. In some cases, the dielectric layer **1006** may be formed using a precursor such as tetraethoxysilane (TEOS) and can be deposited using a suitable process such as chemical vapor deposition (CVD), e.g., low pressure chemical vapor deposition (LPCVD). The dielectric layer **1006** may have a suitable thickness along the vertical direction between 0.1-0.3 microns across the L-BJT regions, which is correlated to the final width of the spacer layer formed therefrom, which in turn defines the base width as described above. Depending on the conformality of the process used to form the spacer, the thickness of a portion of the dielectric layer **1006** on the side walls of the layer stack may be larger by a factor of 1.5-3 (depending on the thickness of the layer stack).

[0240] The fabrication step shown in FIG. **10**D may comprise etching the dielectric layer **1004** to fabricate the spacers **216***b* on the sidewalls of the layer stack. In some cases, the etching process can be an anisotropic or directional etching process (e.g., plasma etching) that etches the dielectric layer **1006** in a vertical direction (e.g., along z-axis). By carefully adjusting the penetration or etching depth of the etching process a portion of the dielectric layer **1006** disposed on the isolating dielectric layers **218** and a portion of the dielectric layer **1006** and the RESURF dielectric layer **717***b* underneath, may be completely removed exposing the HD base well **208** and the LD collector region **710**. In the meantime, given the larger thickness of a portion of the dielectric layer **1006** near and at the side wall of the layer stack remains and form the spacers **216***b* around the layer stack. As the etching rate may decrease proportional to depth, the spacers **216***b* can have a tapered shape from a wide base portion of the spacer (that is in contact with the RESURF dielectric layer **717***b*) toward a top portion of the spacer near the RESURF contact layer **712***b*.

[0241] The final fabrication step shown in FIG. **10**E may comprise depositing a third patterning layer such a third photoresist layer and lithographically patterning the third photoresist layer to generate a third patterned photoresist layer **1008** covering the portions of the isolating dielectric

layers **218**. After patterning the third photoresist layer, the HD emitter region **206** and the HD collector region **707** may be fabricated the base well **208** and the LD collector region **710**, respectively. The HD emitter region **206** and the HD collector **707** region by implanting an n-type dopant (for an NPN L-BJT) or a p-type dopant (e.g., for PNP L-BJT). The layer stack of and the spacers **216***b* of the L-BJT naturally act as a mask for defining the HD emitter region **206** and the HD collector **707** regions. A length the HD emitter region **206** and the HD collector region **707** are determined by a lateral distance (e.g., along y-axis) between one of the isolating dielectric layers **218** and the spacers **216***b*. The length L.sub.B of the base region **201** is substantially equal to a base width of the spacer **216***b* above the base region **201**. Using the layer stack a mask for fabricating the base well **208**, and the layer stack and the spacer **216***b*, as a mask for fabricating the emitter region **206**, results in formation of the base region **201**. As a result, the accuracy of the base length L.sub.B is limited by the accuracy of the dimensions of the spacer **216***b* and the layer stack, and the self-alignment of the base well **208** and the emitter region **206** with the spacer **216***b* and the layer stack, both of which have been highly optimized given decades of development for CMOS fabrication.

[0242] The depth of the HD emitter region **206** and the HD collector region **707** along the vertical direction may be determined by the energy of the implanted dopants. After dopant implantations, the third patterned photoresist layer **1008** may be removed.

[0243] In some implementations, during one or more the fabrication steps shown in FIGS. **10**A-**10**F, corresponding regions or structures a MOS transistor may be fabricated on the common well **212** and/or the substrate **290** on which the L-BJT and the MOS transistor are co-fabricated.

[0244] In some embodiments, the dopant implantation process in the fabrication step for the base well **208** (FIG. **10**B), can be a dedicated implantation process not used for the co-fabrication of the MOS transistors. In such embodiments, a doping profile of the base well **208** can be different from a doping profile of the corresponding regions (e.g., drain or source regions) of a MOS transistor. For example, when the doping profile comprises a Gaussian profile, the peak of the Gaussian profile may be located at the lateral emitter-base interface while for a corresponding source/drain region, the peak can be below the HD/LD interface.

[0245] As mentioned above, in some embodiments, a L-BJT may have an elongated emitter region. In these embodiments, one or more masks used to define a length of the RESURF dielectric layer **717***b* and/or the location position of the layer stack with respect to the isolating dielectric layers **212** may include features having different dimensions for the L-BJT and the MOS transistors. FIG. **10**A shows the doping implantation process for an L-BJT having elongated emitter region **907** and base well **912**. As shown a lateral distance between the spacers **216***b* and the isolating dielectric layers in the emitter side (left) is longer than that of the collector side (right). As a result the base well **912** is longer (along a lateral direction parallel to y-axis) than the LD collector region and the HD emitter region **907** (elongated emitter region) is longer than length of the HD collector region **707** and/or the length of the drain/source regions of one or more MOS transistors or co-fabricated on a common substrate or common well. In some cases, the length of the base well of an L-BJT can be substantially equal to the length of its LD collector region but and the length of its HD emitter region can be longer than length of the HD collector region **707**. In some case, an upper limit for the length of the elongated emitter **907** may be determined based at least in part on a recombination rate or diffusion length of the carrier is the emitter region. In some, examples, a lower limit for the length of an emitter or elongated emitter may be determined by a length (along y-axis) of a conductive contact electrode disposed on the emitter regions **907** or **206**. For example, the length of the conductive contact electrode can be 1.5 to 2 times smaller than the length of the emitter region **907** or **206**.

[0246] In some implementations, the isolating dielectric layers **218** may be thermally grown oxides (also referred to as locally oxidized silicon or LCOS). In some other implementations, the isolating dielectric layers surrounding an L-BJT may be fabricated by etching a trenches in the substrate **290**

and/or common well **212** and depositing a dielectric material (e.g., silicon dioxide) in the trenches (also referred to as shallow trench isolation or STI). FIGS. **11**A-**11**F schematically illustrate selected fabrication steps for an L-BJT having isolating dielectric (STI) layers **1100** disposed in trenches. In some cases, the RESURF dielectric layer **717***b* may be fabricated as part of dielectric deposition process used to fabricate the isolating dielectric layers **1100**. In some cases, the fabrication steps shown in FIGS. **11**A-**11**F are similar to the fabrication steps shown in FIGS. **10**A-**10**F, respectively. The details of the similarities are not reproduced herein for brevity.

[0247] In some cases, a cladding dielectric layer **224** may be disposed on the final structures shown in FIGS. **10**E, **10**F, **11**E, and **11**F, after removing the last patterned photoresist layer. In some cases, the cladding dielectric layer **224** may comprise silicon dioxide.

[0248] Additionally, the fabrication process described with respect to FIG. **10**A-**10**E, may include fabrication of a HD base region in above the base well **208** to provide an ohmic contact to the base region **201**. As described above with respect to FIG. **8**A-**8**C, the HD base region can be fabricated in a corner area between the emitter region **206** and the spacer **216***b* or near an edge of the emitter region **206** opposite to another edge near the spacer **216***b*. As shown in FIG. **8**C, in the latter case, the base well **208** may be partially formed in the common well **212** and a second region **208** having an opposite polarity with respect to the common well **212**. In some cases, the HD base regions **802***a/b* or **806** may be fabricated using a dedicated fabrication process during which a feature a MOS transistor is not fabricated.

[0249] In some cases, the electrical connections to the emitter, base, and collector regions, may comprise the ohmic contacts with a conductive line (e.g., an electrode). In some cases, at least one of the conductive lines may comprise polysilicon having a doping type similar to a region of L-BJT on which the polysilicon is disposed.

[0250] As described above in some embodiments, an emitter region of an L-BJT may be further extended by adding a vertical emitter section to the emitter region, which can further improve the gain of the L-BJT. FIG. **12**A-**12**C schematically illustrate the fabrication process of the vertical emitter section **908** on the emitter region **206** of an L-BJT. FIG. **12**A shows a cross-sectional view of a partially fabricated L-BJT structure during formation before fabricating the vertical emitter section **908**. The emitter region, **206**, base well **208**, HD and LD collector regions **707**, **710**, the isolating oxide layers **218**, the RESURF oxide layer **717***b*, the RESURF contact layer **712***b*, the RESURF layer **714***b*, and the cladding dielectric layer **224** may have been fabricated using standard CMOS fabrication processes. In some examples, these features may have been co-fabricated with the corresponding features of one or more MOS transistors. The fabrication step shown in FIG. **12**B may comprise depositing a photoresist layer and lithographically patterning the photoresist layer to cover cladding dielectric layer **224** except for a region above the emitter region **206** through which a hole is etched to exposing a corresponding area of the emitter region **206**. In the next fabrication step shown in FIG. **12**C the vertical emitter section **908** is fabricated by depositing a semiconducting material having moderate to high conductivity. In some cases, the vertical emitter section may comprise polysilicon. In some cases, vertical emitter section may comprise polysilicon with a dopant of the same type (p or n) of a dopant used to dope the emitter region **206**. In various examples, the vertical emitter section **908** may be fabricated before a metallization process that may electrically connect the base, emitter, or the collector of eth L-BJT to or more components or devices. In some cases, the vertical emitter section **908** may serve as an ohmic contact between a metallization layer and the emitter region **206**.

[0251] In some examples, a thin interfacial dielectric layer **905** (e.g., oxide layer) may be grown at the base of the vertical emitter section **908** and on the emitter region **206**. The thin interfacial dielectric layer **908** may increase the gain of the L-BJT by reducing the gradient of carriers in the emitter region **206** and dropping the base current. In some cases, the interfacial dielectric layer **908** may be a grown layer formed using a controlled growth process such as oxidation or deposition, may be a native oxide, or a combination thereof. In some cases, a thickness of the interfacial

dielectric layer **908** can be as small as 2 atoms of an oxide material. In some, examples, the thickness of the interfacial dielectric layer **908** may be determined based on a desired gain for the corresponding L-BJT. In some other examples, the thickness of the interfacial dielectric layer can be optimized for providing a maximum level of gain within constraints imposed by the other parameter and features of the L-BJT.

[0252] FIGS. **12**D-**12**F schematically illustrate selected fabrication steps for an L-BJT comprising a vertical emitter section and having isolating dielectric layers **1100** disposed in trenches (instead of thermally grown field oxide). In some cases, the fabrication steps shown in FIGS. **12**D-**12**F are identical to the fabrication steps shown in FIGS. **12**A-**12**C, respectively.

[0253] As described above in some embodiments, the base region of a BJT can be a thermally defined base region (instead of being defined by the base width of a spacer). FIG. **13**-**13**C schematically illustrate the fabrication process of the thermally defined base region **901** and the corresponding base well **918** and HD collector region **919**. FIG. **13**A shows a cross-sectional view of a partially fabricated L-BJT structure during formation of the HD collector region **919** and before fabricating the base well **918**. In some cases, the isolating oxide layers **218**, the RESURF oxide layer **717***b*, the RESURF contact layer **712***b*, and the RESURF layer **714***b*, may have been fabricated using standard CMOS fabrication processes. In some examples, these features may have been co-fabricated with the corresponding features of one or more MOS transistors.

[0254] The fabrication step shown in FIG. **13**A may comprise depositing a photoresist layer and lithographically patterning the photoresist layer to generate a patterned photoresist layer **1002** covering portions of the isolating dielectric layers **218** and the RESURF contact layer **712***b* leaving an edge of the layer stack **202***b* near the collector region uncovered. After patterning the photoresist layer, an initial LD collector region **1310** may be formed in the common well **212**, e.g., by implanting an n-type dopant (for an NPN L-BJT) or a p-type (e.g., for PNP L-BJT). The dopant selectively penetrate to a region of the common well **212** covered by the unprotected portion of the RESURF oxide layer **717***b* and form the initial LD collector region **1310**.

[0255] The fabrication step shown in FIG. **13**B may comprise removing the patterned photoresist **1002** and depositing a second photoresist layer and lithographically patterning the second photoresist layer to generate a second patterned photoresist layer **1004** covering the portions of the isolating dielectric layers **218** and the RESURF contact layer **712***b* leaving an edge of the layer stack **202***b* near the emitter/base region uncovered. After patterning the second photoresist layer, an initial LD base well **1308** may be formed in the common well **212**, e.g., by implanting a p-type dopant (for an NPN L-BJT) or an n-type (e.g., for PNP L-BJT).

[0256] The depths of the initial base well **1308** and the initial collector well **1310** along a lateral direction (e.g., along the y-axis), may be determined based on a desired depth of the base well **918** and a length (L.sub.B) of the thermally diffused base region **901**. The length of the initial base well **1308** and the initial collector well **1310** along a vertical direction (e.g., along the z-axis), may be determined based on a desired length of the base well **918** and a length (L.sub.B) of the thermally diffused base region **901**.

[0257] The fabrication step shown in FIG. **13**C comprises removing the patterned photoresist **1004** and elevating the temperature of the structure to form the base well **918**, the thermally diffused base region **901**, and the HD collector region **919**, by thermally diffusing the dopants away from the initial base well **1308** and the initial collector well **1310**. As a result of the lateral diffusion of the dopant from the initial base well **1308**, the base length (L.sub.B) and base depth are determined by the doping profile of the initial base well **1308** and the temperature elevation process. In some cases, a temperature elevation process used for diffusing the initial base well **1308** and LD collector region **1310**, may comprise elevating the temperature of the structure from an initial temperature to a final temperature. In some examples, the temperature may be increased continuously in a linear fashion, nonlinear fashion, or a combination of both. In some examples, the temperature may be increased step wise were during each step the temperature is kept constant or nearly constant to

allow for diffusion of the dopant before next temperature increment. In some cases, a length of the thermally diffused base region **901** along the lateral direction (e.g., a lateral diffusion length of the dopants under the layer stack **202***b*), can be from 50 nm to 100, from 100 nm to 150 nm, from 150 nm to 200 nm, or any range formed by these ranges, or larger or smaller ranges.

[0258] In some cases, the doping profile of the initial base well **1308** may be engineered such when the thermal diffusion process is complete, a doping profile of the resulting base well **918** matches with or is substantially identical to a target doping profile along both the lateral and the vertical directions. In these cases, the thermal diffusion process may simultaneously define L.sub.B and a location of the peak dopant concentration along the vertical axis.

[0259] After fabricating the base well **918** and the LD collector region **919**, a dielectric layer **1006** (e.g., a layer comprising TEOS) may be deposited on the L-BJT structure using the fabrication step described above with respect to FIG. **10**C. The fabrication step shown in FIG. **13**D may comprise a dedicated etching step for etching the dielectric layer **1006** and portions of the RESURF dielectric layer **717***b* on the base well **918** and LD collector region **919**. In some cases a very thin spacer **901** may be left after the etching process (e.g., a vertical etching process). In some cases, the base width of the spacer **901** can be from 1 nm to 5 nm, from 5 nm to 10 nm, from 10 nm to 20 nm, from 20 nm to 30 nm, from 30 nm to 40 nm, or from 40 nm to 50. The final fabrication step shown in FIG. **13**E can be similar to the final fabrication step described above with respect to FIG. **10**E where the HD emitter region **206** and the HD collector region **707** are fabricated by implanting an n-type dopant (for an NPN L-BJT) or a p-type dopant (e.g., for PNP L-BJT). The layer stack **202***b* and the thin spacers **901** of the L-BJT act as a mask for defining the HD emitter region **206** and the HD collector region **707**. While an L-BJT having a thermally diffused base region **911** can be fabricated without the need for fabricating spacers on the side walls of the layer stack **202***b*, in some cases, to maintain the synergy between the fabrication process for the L-BJT and the MOS transistors and to reduce a number of fabrication steps, the dielectric layer **1004** may be still disposed on eth L-BJT structure (after thermal diffusion of the base region). In such cases, the L-BJT is co-fabricated (at least partially) with MOS transistors on a common substrate. However, in some cases (e.g., when the L-BJT is not co-fabricated with MOS transistors), when the deposition of the dielectric layer **1004** after fabricating the thermally defused base region **911** can be skipped. In such cases, the etching process (FIG. **13**D) removes the portions of RESURF dielectric **717***b* layer disposed on the base well **918** and LD collector region **919** but no spacer structure is formed. Subsequently in the final fabrication step (FIG. **13**E), the layer stack **202***b* acts as a mask for defining the HD emitter region **206** and the HD collector region **707**.

[0260] The edge of the layer stack **202***b* self-aligns the edge of the initial base well **1308** and edge of the spacer **901** self-aligns the emitter region **206**. As result the emitter the base-junction is self-alighted with respect to the edge of the spacer **901** or the edge of the layer stack **202***b* (in eth absence of the spacer). The base length and the position of the base-collector junction are determined by the thermal diffusion process. So the doping profile and the length of the thermally diffused base region **901** can be precisely tailored by controlling the doping profile of the initial base well **1308** and a temperature elevation process.

[0261] The doping profile of the thermally diffused base region **901** may comprise a spatially varying dopant concentration that decreases (linearly or nonlinearly) from the edge of the layer stack **202***b* along a lateral direction toward the LD collector region **919**. In contrast, the doping profile of a base region defined by spacers (e.g., the base region **201** in the process shown in FIG. **10**A-**10**E), may comprise a nearly constant or slowly varying dopant concentration along the lateral direction, from the edge of the layer stack **202***b* toward the LD collector region **919** (compared to a variation of dopant concentration in the thermally diffused base region **901**). Advantageously, the doping profile of the thermally diffused base region **901** increases an operational speed of the corresponding L-BJT compared to an L-BJT having base region with nearly constant or slowly varying dopant concentration.

[0262] FIGS. **14**A-**14**D schematically illustrate selected fabrication steps for an L-BJT having isolating dielectric layers **1100** disposed in trenches. In some cases, the RESURF dielectric layer **717***b* may be fabricated as part of dielectric deposition process used to fabricate the isolating dielectric layers **1100**. In some cases, the fabrication steps shown in FIGS. **14**A-**14**E are similar to the fabrication steps shown in FIGS. **13**A-**13**E, respectively.

Lateral Bipolar Junction Transistors with Extended Collector Drift Region

[0263] FIG. **15**A schematically illustrates a cross-sectional view of the L-BJT **906** shown in FIG. **9**D and variation of the voltage **1502** and electric field **1506** along the drift and base regions, **201**, **205** of the L-BJT **906**. The drift region **205** of the L-BJT **906** is extended along the lateral direction from a vertical boundary of the base well **208**, which is aligned with a first edge of the layer stack **202***b*, to a vertical boundary of the LD collector region **710**, which is aligned with a second edge of the layer stack **202***b* opposite to the first edge. The layer stack **202***b* includes a RESURF connector layer **712***b*, a RESURF layer **714***b*, and a RESURF dielectric layer **734***a*. The RESURF connector layer **712***b* is disposed on and is in electric contact with the RESURF layer **714***b*, and the RESURF layer **714***b* is disposed on the RESURF dielectric layer **734***a* that electrically isolates the RESURF layer **714***b* from the drift region **205**. The RESURF layer **714***b* can alter the electric field (E-field) in the drift region **205** by supporting vertical E-field components, e.g., to maintain a magnitude of a lateral E-field component substantially constant or nearly constant along the drift region **205**. In some cases, e.g., when the RESURF connector layer **712***b* is electrically biased to a voltage having a lower magnitude than a voltage provided to the HD collector region **707**, the magnitude of a lateral component of an electric field **1506** generated by applying a voltage between the HD collector region **707** and HD emitter region **206** (also referred to as emitter region), may stay substantially constant or nearly constant along the drift region **205** and base region **201**. In some examples, the constant magnitude of the E-field **1506** (e.g., the lateral component of the E-filed) can be substantially equal to a critical E-field magnitude (E.sub.critical) than can cause one or both of a reverse-bias junction break down in the emitter-base junction and a dielectric breakdown of the RESURF dielectric layer **734***a*.

[0264] As one example, when the potential difference between the HD collector region **707** and HD emitter region **206** is about 5 volts, the voltage **1502** may monotonically, e.g., substantially linearly, decrease from 5 volts at the HD collector region **707** to near zero at the base-emitter junction. As such, the L-BJT **906** can control (e.g., switch) signals comprising a voltage of magnitude of 5 volts. In some cases, an omission of the RESURF layer **714***b* and RESURF contact **712***b*, in the L-BJT **906** may cause the magnitude of the electric field **1504** to monotonically, e.g., substantially linearly increase, along the base region **201** and the drift region **205**. As a result, in the absence of the RESURF layer **714***b* and RESURF contact **7121***b*, a voltage difference of about 5 volts between the HD collector region **707** and HD emitter region **206** may result in a breakdown of one or both of the reverse-biased collector-base junction and the collector-base junction RESURF dielectric layer **734***a*.

[0265] In some cases, the role of the RESURF layer of the L-BJTs **908**, **910**, **902**, **904**, **240** described above with respect to FIGS. **9**E, **9**F, **9**B, **9**C and **7**A, respectively, can be similar or identical to that of the RESURF layer **714***b* of the L-BJT **906**, e.g., maintaining a magnitude of a lateral E-field component constant or nearly constant along the corresponding drift regions. Similarly the variation of E-field and the corresponding voltage along the drift regions of L-BJTs **908**, **910**, **902**, **904**, **240**, and **235** can be similar to those of the L-BJT **906** shown in FIG. **15**A.

[0266] FIG. **15**B schematically illustrates a cross-sectional view of the L-BJT **730** shown in FIG. **7**C and variation of the voltage **1506** and electric field **1506** along the drift and base regions, **201**, **705** of the L-BJT **730**. The drift region **705** of the L-BJT **730** is extended along the lateral direction from a vertical boundary of the base well **208**, which is aligned with an edge of the RESURF layer **732***a*, to a vertical boundary of the HD collector region **707**, which is aligned with an end of the thick isolating dielectric layer **734***b*. When the thick isolating dielectric layer **734***b* is a LOCOS

layer, the end can correspond to a “bird's beak” thereof. The RESURF layer **732***a* comprises a first section **1510***a* on the RESURF dielectric layer **734***a* and a second section disposed on the thick isolating dielectric layer **734***b*. The RESURF dielectric layer **734***a* and the thick isolating dielectric layer **734***b* electrically isolate the RESURF layer **732***a* from the drift region **705**. In some cases, the first and the second sections **1510***a*, **1510***b*, of the RESURF layer **732***a* are referred to as first and second RESURF plates or field plates of the L-BJT **730**. The RESURF layer **732***a* (the first and the second field plates) can alter the electric field (E-field) in the drift region **705** by supporting a vertical E-field component, e.g., to keep a magnitude of a lateral E-field component substantially constant or nearly constant along the drift region **705**. The RESURF layer **732***a* is generally formed of a conductive material and may have a conductivity larger than 10 Ω/sq, larger than 30 Ω/sq, larger than 50 Ω/sq, or larger than 70 Ω/sq. For example, the RESURF layer **732***a* may comprise polysilicon (e.g., n-doped or p-doped polysilicon). However, embodiments are not so limited and the RESURF layer **732***a* may be formed of a metal.

[0267] In some cases, a RESURF connector layer (not shown) may be disposed on the RESURF layer **732***a* to provide an electric contact to the RESURF layer **732***a*. In some cases, e.g., when the RESURF layer **732***a* is electrically biased (e.g., via the RESURF contact layer) to a voltage having a magnitude smaller than the magnitude of a voltage provided to the HD collector region **707**, the magnitude of a lateral component of an electric field **1506** generated in the drift region **705** and the base region **201** (resulting from a voltage applied between the HD collector region **707** and HD emitter region **206**), may stay substantially constant along the drift region **705** and base region **201**. As such, the corresponding voltage may monotonically, e.g., substantially linearly, decrease along the drift region **705** and the base region **201** toward the emitter-base junction. In some examples, the constant magnitude of the lateral component of the E-field **1506** can be substantially equal to the critical E-field magnitude (E.sub.critical) corresponding to a reverse junction breakdown. A length of the drift region **705** of the L-BJT **730** in the lateral direction can be greater than a length of the drift region **205** of the L-BJT **240** (FIG. **27**A. As a result, the drift region **705** and the field plates **1510***a* and **1510***b* of the L-BJT **730** can support a larger voltage drop from the HD collector region **707** to the HD emitter region **206** compared to of the drift region **205** and the RESURF layer (field plate) **714***b* of the L-BJT **906** (FIG. **15**A).

[0268] As one example, when the potential difference between the HD collector region **707** and HD emitter region **206** is about 20 volts, the voltage **1502** may monotonically, e.g., substantially linearly, decrease from 20 volts at the HD collector region **707** to near zero at the base-emitter junction. As such, L-BJT **730** can control (e.g., switch) signals comprising a voltage of magnitude of 20 volts. In some examples by elongating the drift region **705** and one or both field plates **1510***a*, **1510***b*, the voltage drop along the drift region **705** and the base region **201** may be increased up to 80 volts, thereby allowing the L-BJT **730** to control (e.g., switch) signals comprising a voltage having a magnitude of 80 volts.

[0269] With reference to FIG. **15**B, in some cases, omitting the RESURF layer **732***a*, in the L-BJT **730**, may cause the magnitude of the electric field **1504** to monotonically, e.g., substantially linearly, increase along the drift region **705** and the base region **201** of the L-BJT **730**. As a result, in the absence of the RESURF layer **732***a*, a voltage different of 20 volts between the HD collector region **707** and HD emitter region **206** may result in a breakdown of the emitter-base junction of the L-BJT **730**.

[0270] Still referring to FIGS. **15**A and **15**B, in some cases, the L-BJT **906** (FIG. **15**A), which can operate between 0 and 5 volts, may be referred to as a low voltage (LV) L-BJT, and the L-BJT **730**, which can operate between 0 and 80 volts (e.g., depending on the length of its drift region), may be referred to herein as a medium voltage (MV) L-BJT. A comparison between voltage drop across the drift regions of the L-BJT **730** and the L-BJT **906** shows that elongating a length of the drift region in the lateral direction and providing a field plate above the elongated drift region can increase the magnitude of the voltage drop across the drift and base regions. As such, the layer stack and the

corresponding drift region of an L-BJT not only self-align the emitter region, the base well, and the collector region of the L-BJT, but also define a drift region of the L-BJT below a conductive layer (the RESURF LAYER) that may be tailored for increasing an upper limit for the operating voltage of the L-BJT. Advantageously, both L-BJT designs described above can be synergistically co-fabricated with MOS devices having common structural features by using CMOS co-fabrication techniques described herein. For example, the L-BJT **906** can be co-fabricated with, e.g., the low voltage MOS transistor **240** (FIG. **2**), and L-BJT **730** can be co-fabricated with, e.g., the high voltage MOS transistor **740**. In some examples, the base well **208** and the HD collector region **707** of the L-BJT **730** and the LD source region **709** and the HD drain region **721** of the MOS transistor **740** may have at least one common physical dimensions and/or common doping profiles, and can be co-fabricated on a common substrate or a common well in the common substrate. In some examples, the spacer **216***b*, the RESURF layer **732***a*, the RESURF dielectric layer **734***a*, and the thick isolating dielectric layer **734***b* of the L-BJT **730** and the spacer **216***a*, the gate layer **732***b*, the gate **734***c*, and the thick drain dielectric layer **734***d* of the MOS transistor **740** may have at least one common physical dimensions and can be co-fabricated on a common substrate.

[0271] In some examples, the upper limit for the operating voltage (V.sub.m) of an L-BJT can be a voltage above which at least one junction and/or at least one dielectric layer within the L-BJT electrically breaks down by an electric field generated across the dielectric layer or a junction, e.g., a reverse biased PN junction.

[0272] In some embodiments, a collector region of an L-BJT can be tailored to increase its V.sub.m without substantially changing the dimensions and/or configurations of its emitter and base regions. For example, the collector region of the L-BJT **730** may be further extended by increasing the length of the drift region **705** in the lateral direction (e.g., y-direction), elongating the thick isolating dielectric layer **734***b*, and adding an additional field plate above the elongated section of the thick isolating dielectric layer **734***b*.

[0273] Advantageously, by not having to change the emitter and base regions, the fabrication of an L-BJT operating at higher voltages can benefit from the accurate control over the length of the base region (L.sub.B) and co-fabrication of the spacer, RESURF dielectric layer, as well as the emitter, base, and HD collector regions, with the corresponding regions and layers of MOS transistors on a common substrate (as described above with respect to L-BJT **240** (FIG. **2**)). An example of a high voltage (HV) L-BJT **350** having an extended drift region was described above with respect to FIG. **3**B. More details about L-BJT **350** and related L-BJT designs capable of operating at higher voltages (e.g., larger than 80 volts) are described below. In some cases, an L-BJT having an extended drift region and a field plate (e.g., a metallic field plate) in addition to the RESURF layer **732***a*, may be referred to herein as an HV L-BJT. In some examples, an HV L-BJT may have a V.sub.m greater than 80 volts, greater than 90 volts, greater than 100 volts, greater than 150 volts, greater than 200 volts, greater than 250 volts, greater than 300 volts, or a value in a range defined by any of these values.

[0274] FIG. **16**A schematically illustrates a cross-sectional view of an example L-BJT **350** having an elongated drift region, herein referred to as an extended drift region, comprising the drift region **205** and a drift region extension **304***b*. In some cases, the elongated drift region extending between the HD collector region **707** and the base well **206** may be referred to as the drift region of the L-BJT **350**. The L-BJT **350** further comprises a layer stack, and one or more field plates above the drift region extension. The drift region **205** extends in the lateral direction from a first end to a second end, and the drift region extension **304***b* extends in the lateral direction from the second end of the drift region **205** to a third end. The extended drift region extends from the first end of the drift region **205** to the third end of the drift region extension **304***b*. A length of the extended drift region in the lateral direction can be from 0.5 to 2.0 microns, or from 2.0 to 5.0 microns, from 5.0 to 15.0 microns, from 15.0 to 25.0 microns, or a value in a range defined by any of these values or smaller or larger. A length of the drift region **205** in the lateral direction can be from 0.18 to 0.6

microns, or a value in a range defined by any of these values or smaller or larger. A length of the extended drift region **304***b* can be from 0.5 to 25.0 microns, or a value in a range defined by any of these values or smaller or larger.

[0275] Similar to L-BJT **240**, the HV L-BJT **350** includes an emitter region **206** and a base region **201** at one end of the extended drift region, and an HD collector region **707** at the other end of the extended drift region.

[0276] Still referring to FIG. **16**A, the layer stack of the HV L-BJT **350** comprises a RESURF dielectric layer **734***a* over the drift region **205**, and a RESURF layer herein referred to as first field plate **1510***a* disposed on the RESURF dielectric layer **734***a*. In some cases, a RESURF connection layer may be disposed on the first field plate **1510***a*. In some cases, a thick isolating dielectric layer **1614** may be disposed above the drift region extension **304***b*. The thick isolating dielectric layer **1614** can extend from an edge of the RESURF dielectric layer **734***a* toward the HD collector region **707**. A thickness of a thick isolating dielectric layer **1614** along the vertical direction (e.g., along z-axis) can be larger than a thickness of the RESURF dielectric layer **734** along the vertical direction. In various implementations, a difference between a thickness of the thick isolating dielectric layer **1614** and RESURF dielectric layer **734** along can be from 0.01 to 0.015 microns. In some examples, thickness of the thick isolating dielectric layer **1614** can be from 0.3 to 0.5 microns, a value in a range defined by any of these values or smaller or larger. In various implementations, a length of the thick dielectric layer **1614** can be larger than 20%, 30%, 40%, 50%, or 60% of the length the extended drift region or a lateral distance between the base well **208** and the HD collector region **707**.

[0277] A second field plate **1510***b* may be disposed above a portion of the thick isolating dielectric layer **1614**. In some cases, the second field plate **1510***b* may be in contact with a top surface of the thick isolating dielectric layer **1614**. In some cases, the first and the second field plates **1510***a*, **1510***b* may comprise the same material (e.g., a conductive material such as n-doped polysilicon). In some cases, the first and the second field plates **1510***a*, **1510***b* can be two sections of a single RESURF layer disposed (e.g., conformally) on the RESURF dielectric layer and at least a portion of the thick isolating dielectric layer **1614**.

[0278] The extended drift region can be laterally extended from a vertical boundary of the base well **208** below the first field plate **734***a* to a vertical boundary of the HD collector region **707**). In some cases the vertical boundary of the base well **208** can be aligned with an edge of the first field plate **734***a*.

[0279] In some cases, the emitter region **206** (also referred to as HD emitter region) of the L-BJT **350** may be aligned with an edge of a spacer **216***b* formed on a sidewall of the first field plate **1510***a* (similar to L-BJT **240**). As such, during a fabrication process, the length of a base region of the L-BJT **350** may be defined by a width of a bottom portion of the spacer **216***b*. In some cases, at least the base well **208**, the emitter region **206**, the spacer **216***b*, the first field plate **1510***a*, and the RESURF dielectric layer **734***a* of the L-BJT **350** may be co-fabricated with the corresponding regions and features of a MOS transistor (e.g., the MOS transistor **300** (FIG. **3**A) or the MOS transistor **280** (FIG. **2**). In some cases, the L-BJT **350** can be co-fabricated with the MOS transistor **300** (e.g., a DMOS) on a common substrate (e.g., in a common well **212** formed in the substrate **290**). For example, a gate layer in the gate stack **202***a* of the MOS transistor **300** may serve as a gate contact (corresponding to the first field plate **1510***a*), and its gate stack extension **302***a* may include a first drain plate (corresponding to the second field plate **1510***b*) disposed on a thick drain dielectric layer **1614** (corresponding to the thick isolating dielectric layer), and a second drain plate (corresponding to the third field plate) extended over the thick channel dielectric layer. In some cases, the first, second, and third field plates **1510***a*, **1510***b*, **1612**, the thick isolating dielectric layer **1614**, of the L-BJT **350** and the corresponding plates and layers of the MOS transistor **300** may have at least one common physical dimension and/or material and can be co-fabricated (e.g., during the same fabrication steps) on a common substrate (e.g., over common well in the common

substrate).
[0280] The dopant concentration distribution **1616** shows the variation of average doping concentration level in the L-BJT **350** along the lateral direction (e.g., y-axis). A dopant concentration (D.sub.E) in the emitter region can be larger than a dopant concentration (D.sub.B) in the base region. A dopant concentration (DDR) in the extended drift region can be smaller than D.sub.B and DDR. A dopant concentration (D.sub.CHD) in the HD collector region can be from 10.sup.20 to 10.sup.21 cm.sup.3. A dopant concentration (D.sub.E) in the emitter region **206** can be from 10.sup.20 to 10.sup.21 cm.sup.−3. A dopant concentration (D.sub.B) in the base well can be from 10.sup.18 to 10.sup.19 cm.sup.−3. In some cases, a dopant profile of the base region can have a peak near or at the lateral boundary between the emitter region **206** and the base well **208**.
[0281] In some cases, the dielectric layers and field plates in the extended layer stack of the L-BJT **350** may allow for increasing DDR compared to that of an L-BJT having an extended drift region without the field plates reduce the resistance of the drift region.
[0282] In some cases, in addition to altering the E-field in the extended drift region, the field plates may dissipate heat generated by the L-BJT **350** and thereby improve the performance of the L-BJT **350** by allowing larger currents to follow across different region of the L-BJT **350** before the onset of current limiting thermal effects.
[0283] FIG. **16**B schematically illustrates a cross-sectional view of the L-BJT **350** shown in FIG. **16**A and variation of the electric field along the extended drift region of the L-BJT. As described above, the field plates **1510***a*, **1510***b*, **1612**, produce a vertical E-field component (E.sub.RESURF) in the extended drift region. The total E-field (E.sub.tot) at any point along the extended drift region can correspond to a vector sum of the emitter-base junction E-field and the E.sub.RESURF. In some cases, at least the magnitude of the lateral component of the E.sub.tot (E.sub.tot-L) **1506** remains constant or nearly constant along the extended drift region from the base-emitter junction to the HD collector region (in the lateral direction). In some examples, the lateral component of the E.sub.tot along the extended drift region, from HD collector region **707** to the base well **208**, may change less than 2%, less than 4%, less than 6%, less than 8%, or less than 10% of its vale at the boundary of the base well **208**. In some examples, the lateral component of the E.sub.tot along the extended drift region, from HD collector region **707** to the base well **208**, may remain less than threshold value (e.g., E.sub.critical) that may cause break down in a oxide layer (e.g., RESURF dielectric layer **734***a*) or a junction (e.g., base-collector junction), of an L-BJT (e.g., an L-BJT having an extended drift region).
[0284] The voltage drop from the HD collector region **707** to HD emitter region **206** is equal to the area under the curve **1506** or |E.sub.tot-L/×L.sub.drift, where L.sub.drift is the length of the extended drift region in the lateral direction. In some cases, V.sub.m for the L-BJT **350** can be substantially equal to |E.sub.critical|×L.sub.drift, where E.sub.critical is an E-field magnitude that can cause electrical break down in the emitter-base junction or the RESURF dielectric layer **734***a*. In other words, the minimum length of the extended drift region for a desired V.sub.m, or the V.sub.m for a given L.sub.drift are constrained by E.sub.critical that depends on the material and thickness of the RESURF dielectric layer, and the material and doping characteristics of the emitter-base junction. In the absence of the field plates, **1510***a*, **1510***b*, and **1612**, the magnitude of the E.sub.tot-L **1504** could monotonically decrease, e.g., substantially linearly decrease, along the extended drift region from the base-emitter junction to the HD collector region (in the lateral direction). As such, to for the E.sub.tot-L to stay below or close to E.sub.critical near the base-emitter junction, the length of the drift region should be longer in the absence of the field plates. In the absence of the field plates, V.sub.m can be correspond to or approximated as |E.sub.critical| ×(L′.sub.drift/2), or the area below E.sub.tot-L **1504** line. So for a given V.sub.m and E.sub.critical the length of the extended drift region (L′.sub.drift) in the absence of the field plates can be about two times larger than the length (L.sub.drift) of the extended drift region in the presence of the field plates for the L-BJT **350**.

[0285] In some embodiments, V.sub.m can be further increased by elongating the extended drift region and adding yet an additional (e.g., a fourth) field plate extended over at least a portion of the elongated section of the extended drift region. In some cases, the thick isolating dielectric layer **1614** may be elongated to provide isolation between the additional field plate and the elongated section of the extended drift region. FIG. **16**C schematically illustrates a side cross-sectional view of an HV L-BJT **1600** having a yet longer drift region extension **304***b* and thick isolating dielectric layer **1614** compared to HV L-BJT **350**. The HV L-BJT **1600** also includes a fourth field plate **1618** that is laterally extended from a distal end of the third field plate **1612**, with respect to the second field plate **1510***b*, toward the HD collector region **707**. In some cases, the third and fourth field plates **1612**, **1618**, are substantially parallel to the top surface of the substrate or the top surface of the thick isolating dielectric layer **1614**. A vertical distance h.sub.1 (e.g., along z-axis) between the third field plate **1612** and the top surface of the thick isolating layer **1614** can be larger than a vertical distance h.sub.2 (e.g., along z-axis) between the fourth field plate **1618** and the top surface the thick isolating layer **1614**. In some cases, the third and fourth field plates **1612**, **1618**, can be fabricated in two different metallization layers (e.g., adjacent metallization layers of an IC), where one metallization layer is above the other. In various implementations, a difference between h.sub.1 and h.sub.2 can be from 0.5 to 1.0 microns. In some examples, h.sub.1 and h.sub.2 can be from 0.5 to 2.5 microns, or a value in any range defined by these values or smaller or larger.
[0286] In various implementations, the third and the fourth field plates **1612**, **1618**, may cover at least 20%, 30%, 40%, 50%, or 60% of a lateral length of the thick isolating dielectric layer **1614**. In various implementations, the third field plate **1612** may cover at least 20%, 30%, 40%, 50%, or 60% of the lateral length thick isolating dielectric layer **1614**. In various implementations, the third and the fourth field plates **1612**, **1618**, may cover at least 20%, 30%, 40%, 50%, or 60% of a lateral length of the extended drift region. In various implementations, the third field plate **1612** may cover at least 20%, 30%, 40%, 50%, or 60% of the lateral length of the extended drift region.
[0287] In some cases, a doping profile of the L-BJT **1600** can be similar to the doping profile **1616** described with respect to L-BJT **350**. The placement of the HD base regions of the L-BJT **350** and L-BJT **1600**, with respect to the corresponding HD emitter regions **206**, is similar to the placement of the HD base regions **802***a*/**802***b* in the L-BJT **800** (FIGS. **8**A and **8**B).
[0288] The variations of the voltage **1602** and electric field **1506** along the extended drift region are shown below the corresponding drift region and drift region extension **304***b*. As shown in FIG. **16**C, the isolating dielectric layers and field plates can maintain the lateral component of the E-field **1506** constant or nearly constant along the drift region. As such the voltage **1602** monotonically, e.g., substantially linearly, drops from the HD collector region **707** toward the HD emitter region **206**. Similar to the L-BJT **350** (FIG. **3**B), V.sub.m for the L-BJT **1600** is equal to |E.sub.critical| ×L.sub.drift. Given that L.sub.drift is longer for the L-BJT **1600**, V.sub.m can be larger for the L-BJT **1600** compared to the L-BJT **350**. In the example, shown the V.sub.m for the L-BJT **1600** is about 250 V.
[0289] FIG. **17** schematically illustrates V.sub.m (the upper limit for the operating voltage) plotted against the length of the drift region for four different L-BJT designs and structures described herein. The low voltage (LV) L-BJT **906** and similar L-BJT designs (e.g., L-BJT **908**, **910**, **902**, **904**, **240**, or **235**) that include a single field plate over a thin dielectric layer (RESURF dielectric layer) and/or have drift region length less than 1.0 microns, may have a V.sub.m smaller or equal to 5 volts. The medium voltage (MV) L-BJT **904** and similar L-BJT designs that include two field plates, one disposed on a thin dielectric layer and the other on a thick dielectric layer, and/or have a drift region length greater than 1.0 microns but smaller than 5.0 microns, may have a V.sub.m larger than 5 volts but smaller than or equal to 80 volts. The High Voltage (HV) L-BJT **350** and similar L-BJT designs that include three field plates, one over a thin dielectric layer and two over a thick dielectric layer and/or have a drift region length greater than 5.0 microns but smaller than 15.0 microns, may have a V.sub.m larger than 80 volts but smaller than or equal to 150 volts. The

HV L-BJT **1600** and similar L-BJT designs that include four field plates, one over a thin dielectric layer and three over a thick dielectric layer, and/or have a drift region length greater than 15.0 microns, may have a V.sub.m larger than 150 volts.

[0290] In some cases, an L-BJT having a drift region length less than 1.0 microns can be an LV L-BJT with a V.sub.m less than 5 volts, an L-BJT having a drift region larger than 1.0 and smaller than 5.0 microns can be an MV L-BJT with a V.sub.m greater than 5 volts and less than 80 volts, an L-BJT having a drift region length larger than 5.0 microns and smaller than 15.0 microns can be an HV L-BJT with a V.sub.m greater than 80 volts and less than 150 volts, and an L-BJT having a drift region length larger than 15.0 microns can be an HV L-BJT with a V.sub.m up to 150 volts or greater.

[0291] In some cases, a length of the extended drift region of the L-BJT **350** or the L-BJT **1600**, in the lateral direction, can be substantially equal to a length of the first field plate **1510***a* in the lateral direction. In some cases, a length of the drift region extension **304***b* of the L-BJT **350** or the L-BJT **1600** can be substantially equal to the length of the thick isolating dielectric layer **1614**.

[0292] In various implementations, all the field plates of an L-BJT are electrically connected to each other. In some examples, the third field plate **1612** can be electrically connected to the second field plate **1510***b* via a first vertical conductive line (e.g., a first conductive via), and the fourth field plate **1618** can be electrically connected to the second field plate **1612** via a second vertical conductive line (e.g., a second conductive via). In some embodiments, the first and the second field plates **1510***a*, **1510***b*, may comprise polysilicon. In some embodiments, the third and fourth field plates **1612**, **1618**, may comprise metal (e.g., copper, gold, aluminum, chromium, or an alloy made of two or more metals). In various examples, one or more field plates may comprise a doped semiconductor (e.g., doped polysilicon). In various examples, one or more field plates may comprise a metal or metallic alloy.

[0293] In some examples, the field plates **1510***a*, **1510***b*, **1612**, and **1618**, may be electrically connected to a potential (referred to as RESURF potential) having a magnitude less than the magnitude of a potential applied to the HD collector region **707**. For example, the field plates **1510***a*, **1510***b*, **1612**, and **1618**, may be electrically connected to the emitter region **206** or potential provided to the emitter region **206**. In some example, the field plates **1510***a*, **1510***b*, **1612**, and **1618**, may be electrically connected to a ground potential. In various implementations, a potential of the field plates **1510***a*, **1510***b*, **1612**, and **1618**, may remain constant or nearly constant during the operation of the corresponding L-BJT.

[0294] In some embodiments, the extended drift region can be further elongated and more field plates may be added over of the elongated section of the extended drift region to further increase V.sub.m of an HV L-BJT. A vertical distance between a field plate and the top surface of the thick dielectric layer **1614** (or a top surface of the drift region extension **304***b*) may be smaller than a vertical distance between a subsequent field plate and the top surface of the thick dielectric layer **1614**. In some cases, the increasing vertical distances of the subsequent field plates from a surface can contribute in maintaining a lateral component of the E-field substantially constant along the extended drift region and thereby increasing V.sub.m.

[0295] In some examples, the field plates **1510***a*, **1510***b*, **1612**, and **1618**, and any additional field plate(s), may be fabricated on different metallization layers (e.g., metallization layers of an IC).

[0296] In various embodiments, an HV L-BJT, having an extended drift region and field plates, may be electrically isolated from low or medium voltage electronic devices (e.g., LV and MV L-BJTs and MOS transistors) fabricated on the same substrate, to avoid perturbation or damage to those devices due to unintended coupling of a high level voltage from the HV L-BJT. In some cases, electrical isolation may comprise complete isolation of the HV L-BJT both in the lateral and vertical directions to block carrier transport or E-field coupling through nearly all regions of the HV L-BJT to a region of the substrate comprising low or medium voltage devices. In some cases, a complete isolation may be achieved using a combination of a buried dielectric layer (e.g., a buried

oxide layer) and deep trenches filled with a dielectric material (e.g., deep trench oxides), or isolating dielectric layers near the top surface of the device (e.g., LOCOS field oxide layers or shallow trenches filled with a dielectric material).

[0297] FIG. **18** schematically illustrates a side cross-sectional view of an HV L-BJT **1800** with extended drift region, which is fully isolated. In some cases, L-BJT **1800** can be laterally isolated by the isolation dielectric layers **218** (e.g., field oxide or shallow trench isolation (STI) layers), and vertically isolated by a buried dielectric layer **909** (e.g., buried oxide layer). In some cases, the L-BJT **1800** can be laterally isolated by the shallow dielectric filled trenches (e.g., shallow trench oxide also referred to as STI) similar to the isolation dielectric layers **1100**, described above with respect to FIGS. **11**A-**11**F. L-BJT **1800** may comprise one or more features described above with respect to the L-BJT **350** or L-BJT **1600**.

[0298] In some examples, the buried dielectric layer **909** may be in contact with the dielectric layers **218**. In some examples, a vertical gap or distance (e.g., along z-axis) between a bottom surface of the dielectric layer **218** and a top surface of the buried dielectric layer **909** can be less than 5 nm, less than 10 nm, or less than 20 nm. In some cases, the extended drift region of the L-BJT **1800** may comprise a drift region **205** below a layer stack and a drift region extension **304***b*. The layer stack may comprise a RESURF dielectric layer **734***a*, and a RESURF layer (or a first field plate) **732***a* disposed on RESURF dielectric layer **734***a*. The base well of the L-BJT **1800** can be vertically extended from a top surface of the buried dielectric layer **909** to a cladding dielectric layer **224**, e.g., a passivation layer, disposed on the L-BJT **1800** along its entire length. A thickness of the emitter region **206** and a thickness of the HD collector region **707** can be substantially equal to the thickness of the base well along the vertical direction.

[0299] The drift region **205** of the L-BJT **1800** is extended in the vertical direction from a top surface of the buried dielectric layer **909** to a bottom surface of the RESURF dielectric layer **734***a*. The drift region extension **304***b* of the L-BJT **1800** is bound in the vertical direction by the cladding dielectric layer **224**, and the top surface of the buried dielectric layer **909**. In some embodiments, the fully isolated L-BJT **1800** may not include a thick isolating dielectric layer above its drift region extension **304***b*. The field plates of the L-BJT **1800** include the first field plate (RESURF layer) **732***a*, a second field plate **1812**, and a second field plate **1818**. In some cases, the second field plate **1812** may be extended in the lateral direction from a first end approximately aligned with a middle region of the first field plate **732***a* to a second end above the drift region extension **304***b*. The third field plate **1818** may be extended in the lateral direction from a point near the second end of the first field plate **1812** away from the first field plate **1812**.

[0300] In some cases, the field plates **1812**, **1818** of the L-BJT **1800** may maintain a magnitude of the lateral E-field component in the drift region **304***b* constant or nearly constant from the emitter-base junction to the HD collector region **707** of the L-BJT **1800**. As such the L-BJT **1800** may have a V.sub.m larger than 80 volts.

[0301] In some implementations, the length of the extended drift region of the L-BJT **1800** can be further increased by increasing the lateral distance between the base well and the HD collector region **707** and adding a fourth field plate above the third field plate **1818**.

[0302] In some cases, a doping profile of the L-BJT **1800** can be similar to the doping profile **1616** described with respect to L-BJT **350**.

[0303] In some embodiments any of the L-BJT's (e.g., L-BJT **240**, **730**, **350**, or **1600**) described above can be isolated in the lateral direction using deep trenches filled with a dielectric material (e.g., an oxide). These deep trenches may be extended from the isolating dielectric layers **218** to a buried dielectric layer that vertically isolates (electrically) an upper region of the substrate **290** below the doped wells, in which the L-BJT is formed, from a lower region of the substrate **290**.

FIG. **19** schematically illustrates an example HV L-BJT **1900** having an extended drift region, which is fully isolated using deep dielectric trenches **1902** and a buried dielectric layer **1904**. The fully isolated L-BJT **1900** comprises one or more features described above with respect to L-BJT

1600. The placement of the HD base region **806** with respect to the HD emitter region **206** for L-BJT **1900** is similar to the placement of the HD base region **806** of the L-BJT **804**. In some examples, a height of a deep dielectric trench **1902** along the vertical direction (z-axis), can be from 1 to 5 microns, from 5 to 10 microns, from 10 to 15 microns, from 15 to 20 microns, or larger values.

[0304] FIG. **20** schematically illustrates the depletion regions of the L-BJT **2000** at three different magnitudes of bias or input voltages (e.g., voltages applied between the HD collector region **707** and the HD emitter region **206**. The evolution of the depletion regions of the L-BJT **350**, **1600**, **1800** and similar L-BJT designs having an extended drift region can be at least qualitatively similar to the evolution of the depletion regions of the L-BJT under the same biasing conditions.

[0305] In some cases, the depletion regions of the L-BJT **2000** may be formed by two boundaries, including a first boundary near the emitter-base junction and the base well, and a second boundary surrounding the HD collector region **707** and extending into the collector region and sometimes a portion of the substrate below the collector region.

[0306] As one example, at a relatively low bias voltage of about 5 volts, the first boundary **2102***a* may extend from the base region to a region below the base well, and the second boundary **2104***a* may extend along the entire drift region including a portion of the substrate below the collector region.

[0307] As another example, at a medium bias voltage of about 80 volts, the first boundary **2102***b* may become confined in the well and surround the HD emitter region **206** and HD base region **806**, and the second boundary **2104***b* may be contracted back toward the HD collector region and may entirely be in the drift region extension.

[0308] As yet another example, at a relatively high bias voltage of about 250 volts, the first boundary **2102***c* may remain substantially unchanged compared to the first boundary **2102***b* under 80 volt bias, while the second boundary **2104***c* may further contracted and be confined around the HD collector region.

[0309] While fully isolating an HV L-BJT using shallow or deep dielectric filled trenches and a buried dielectric layer based on the architectures described above may highly effectively prevent current and/or voltage coupling to low or medium voltage devices fabricated on the same substrate, implementation of these isolation structures can be costly, and significantly increases the complexity and cycle time of the fabrication process. Fabricating deep trenches and filling them with dielectric material requires additional process steps that are longer and more complicated compared to local oxidation of silicon (LOCOS) and fabrication of shallow trench isolation (STI) layers. The buried dielectric layer is typically embedded in the wafer or the substrate on which the HV L-BJT is fabricated. An example, of such wafer is silicon-on-oxide (SOI) wafer that is significantly more expensive than a regular silicon wafer.

[0310] To reduce cost, complexity, and cycle time for fabricating HV L-BJT properly isolated from the low or medium voltage devices fabricated on the same substrate, in some cases, the high voltage region of the device may be isolated from the other regions by thick isolating dielectric layers (e.g., fabricated by LOCOS) on the surface of the device. As described above, in an HV L-BJT the high voltage provided to HD collector region drops along the extended drift region. As such, electrically isolating the HD collector region and the extended drift region from the base region, and the emitter region can decouple the high voltage from the substrate on which other electronic devices are fabricated.

[0311] FIG. **21** schematically illustrates a cross-sectional view of an HV L-BJT **2100** with an isolated drift region extension **2102** and four field plates **1510***a*, **150***b*, **1612**, **1618**. The architecture of the HV L-BJT **2100** has been modified with respect to the HV L-BJT **1600** (FIG. **16**C) to allow for vertical isolation of the HD collector region **2101** and the drift region extension **2102** from the rest of the device, which operates at a low or medium voltage level, using a second thick dielectric layer (e.g., a second field oxide layer) **2103**. The HD collector region **2101** and the drift region

extension **2102** have the same polarity but the drift region extension **2102** can be an LD region having a smaller dopant concentration.

[0312] The HV-LBJT **2100** may include an emitter region **206**, a base well **208**, spacers **216***b*, a first field plate **1510***a*, a second field plate **1510***b*, a RESURF dielectric layer **734***a*, and a thick isolating dielectric layer **1614**. In some implementations, doping profiles, physical dimensions, configuration, and relative alignment of the emitter region **206**, the base well **208**, the spacer **216***b*, the first field plate **1510***a*, the second field plate **1510***b*, a RESURF dielectric layer **734***a*, and the thick isolating dielectric layer **1614** of the HV L-BJT **2100** may be identical or similar to those of the HV L-BJT **1600** (FIG. **16**C) or **350** (FIGS. **16**A and **16**B), the detailed description of which are not repeated herein for brevity.

[0313] The RESURF dielectric layer **734***a*, the thick isolating dielectric layer **1614**, and the base well **208** may be formed in or disposed on a main well (e.g., a common well) **2114** having a polarity opposite to the polarity of the drift region extension **2102**. In some cases, the base well **208** may be partially formed in the main well **2114** and a second well **214** having a polarity opposite to that of the base well **208**. In some cases, a vertical boundary between the second well **214** and the main well **2114**, below the base well **208**, can be aligned with a vertical boundary between the emitter region and base well, below the spacer **216***b*.

[0314] In some cases, the second thick isolating dielectric layer **2103** is partially disposed or grown on the main well **2114** and a third well **2104** having the same polarity as the drift region extension **2102** (opposite to the polarity of the main well **2114**).

[0315] The HV L-BJT **2100** also includes a third and a fourth field plate **1612**, **1618** that are laterally extended above a portion of the drift region extension **2102**. In some cases, the third and fourth field plates **1612**, **1618**, are parallel to the top surface drift region extension **2102**. A vertical distance h.sub.3 (e.g., along z-axis) between the third field plate **1612** and the top surface of the drift region extension **2102** can be larger than a vertical distance h.sub.4 (e.g., along z-axis) between the fourth field plate **1618** and the top surface the drift region extension **2102**. In various implementations, a difference between h.sub.3 and h.sub.4 can be from 0.5 to 1.0 microns. In some examples, h.sub.1 and h.sub.2 can be from 0.5 to 2.5 microns, or any value in a range defined by any of these values or smaller or larger. In some cases, the third and fourth field plates **1612**, **1618**, can be fabricated in two different metallization layers (e.g., metallization layers of an IC) and can be electrically connected via a vertical conductive line.

[0316] Similar to HV L-BJT **1600**, the third and the fourth field plates **1612**, **1618**, may maintain a lateral component of the E-field in the drift region extension **2102**, constant along drift region extension **2102**. A section **2116** of the main well **2114** below the drift region extension **2102** may function as an auxiliary field plate further reducing the variation of the lateral component of the E-field in the drift region extension **2102**.

[0317] The third and fourth field plates **1612**, **1618**, are electrically connected to the first and second field plates **1510***a*, **1510***b*, e.g., via a conductive line **2112** having at least one lateral section and one vertical section.

[0318] In some cases, the drift region extension **2102** of the HV L-BJT **2100** may be electrically connected to the main well **2114** via an LD connecting layer **2125** and an HD connecting region **2106**.

[0319] When the HV L-BJT **2100** is biased, e.g., a potential difference is generated between the HD collector region **2101** and the emitter region **206**, the voltage variation the device may have a piecewise behavior. For example, the illustrated voltage curve in FIG. **21** shows relatively constant voltage curve portions **2110***a*, **2110***c* and **2110***e*, and monotonically varying voltage curve portions **2110***b*, **2110***d*. As illustrated, the voltage remains relatively or nearly constant along the HD collector region **2101** as shown by the voltage curve portion **2110***e*, varies (e.g., monotonically, e.g., substantially linearly) along the drift extension region **2102** as shown by the voltage curve portion **2110***d*, remains relatively or nearly constant along the region extending from a boundary of

the drift region extension **2102** to an edge of the second field plate **1510***b* as shown by the voltage curve portion **2110***c*, varies (e.g., monotonically, e.g., substantially linearly) along the drift region under the first and the second field plates **1510***a* and **1510***b* as shown by the voltage curve portion **2110***b*, and remains relatively or nearly constant in the base region as shown by the voltage curve portion **2110***a*. As such the voltage drops from an input voltage (V.sub.in) level applied to the HD collector region to an intermediate voltage (V.sub.Mid) along the drift region extension **2102**, which is electrically isolated from the substrate along the vertical direction, and from the first voltage to a final voltage (V.sub.Fin) along the drift region. In some cases, the first voltage can be equal less than 5 volts. In some cases, the ratio between the intermediate voltage and the input voltage (V.sub.Mid/V.sub.in) can be less than 50%, less than 40%, less than 30%, less than 20%, or less than 10%. In some cases, the voltage drop in the drift region extension (**2102**) may be increased or the ratio V.sub.Mid/V.sub.in can be decreases by elongating the drift region extension **2102**. To support a monotonic or substantially linear voltage drop along the drift region extension **2102**, more field plates may be added above the drift region extension **2102**. A vertical distance of each field plate from the top surface of the drift region extension **2102** can be smaller than a vertical distance of a subsequent field plate from the top surface of the drift region extension **2102**.

[0320] In some cases, the emitter region **206**, the base well **208**, the spacer **216***b*, the first field plate **1510***a*, the second field plate **1510***b*, and the thick isolating dielectric layer **1614** of the HV L-BJT **2100** and corresponding features of a MOS transistor (e.g., MOS transistor **280**), an MV MOS or DMOS transistor (e.g., the MOS transistor **740**), or an HV MOS or DMOS transistor (e.g., the MOS transistor **300**) may be co-fabricated and have a common physical dimension.

[0321] In some embodiments, a length of the thick isolating dielectric layer **1614** in the lateral direction, can be from 0.5 to 5.0 micrometers, or any value in a range defined by any of these values or larger or smaller.

[0322] In some embodiments, a length of the first field plate **1510***a* (RESURF layer) can be from 0.18 to 1.0 micrometers, or any value in a range defined by any of these values or larger or smaller.

[0323] In some embodiments, a length of the second field plate **1510***b* (RESURF layer) can be from 0.5 to 5.0 micrometers, or any value in a range defined by any of these values or larger or smaller.

[0324] In some embodiments, a length of the third or fourth field plates **1612**, **1618**, can be from 1 to 15 micrometers, or any value in a range defined by any of these values or larger or smaller.

[0325] In some examples, a lateral length of the third field plate **1612** can be from 1-5 μm, and the lateral length of the fourth field plate can be from 1-15μ. Their vertical distance from the top surface of the drift region extension **2102** can be 0.5 and 2.5 μm, respectively.

[0326] In some embodiments, the third and fourth field plates **1612**, **1618**, may cover 50% to 60%, 60% to 70%, 70% to 80%, 80% to 90%, or 90% to 100%, or any percentage in a range defined by any of these values or larger or smaller, of the length of the thick isolating dielectric layer **1614**.

[0327] While the region below the base well of the L-BJTs **350**, **1600**, and **2100** comprises two regions having opposite polarities, in some cases, the region below these base wells may not comprise two regions having opposite polarities. As described above, splitting the region below the base well into two regions with opposite polarities and aligning a vertical interface between the two regions with the emitter-base junction may improve the performance of the L-BJT.

[0328] In various implementations, the L-BJTs having extended drift regions (e.g., L-BJT **350** (FIG. **16**A, **16**B), **1600** (FIG. **18**), **1800** (FIG. **18**)), can be NPN or PNP bipolar transistors. For example, an n-type emitter region, a p-type base well **208**, n-type extended drift region, and an n-type HD collector region may form an NPN bipolar transistor, and a p-type emitter region, an n-type base well **208**, p-type extended drift region, and an p-type HD collector region may form a PNP bipolar transistor. In some embodiments, an L-BJT having extended drift region (e.g., L-BJT **350**, **1600**, **1800**), can be at least partially co-fabricated with a HV MOS transistor (e.g., a DMOS) having an extended channel region or an LV MOS transistor. In some embodiments, one or more

features of the HV L-BJT and the HV MOS transistor (or an LV MOS transistor) may have common physical dimensions. For example, a bottom width of a spacer, a length of the RESURF layer and the RESURF dielectric layer, a length of the emitter region, a length of the base well, or a length of the HD collector region of the HV L-BJT, can be substantially equal to a bottom width of a spacer, a length of the gate layer and the gate dielectric layer, a length of the HD source region, a length of the LD source region, or a length of the HD drain region of the HV MOS transistor.
[0329] In some implementations, and the corresponding features of the HV MOS transistor and the HV L-BJT, e.g., those features having common physical dimensions, may be synergistically co-fabricated during the same fabrication step(s) on a common substrate. Unlike the HD and LD source regions of the HV MOS transistor, the emitter region and the base well of the HV-LBJT do not have same polarity, in both cases the boundary of the LD and HD regions are defined by the RESURF dielectric layers and the spacers.
[0330] As mentioned above, the structure and configuration of the base well, base region, emitter region, RESURF layer, and the RESURF layer stack in an HV L-BJT having an extended drift region (e.g., the HV L-BJT **350** or HV L-BJT **1600**) can be identical to an LV L-BJT (e.g., the L-BJT **240**). As such fabrication steps described above with respect to co-fabrication of the L-BJT **240** with the MOST transistor **280** on a common substrate may be used to co-fabricate at least the base well, base region, emitter region, RESURF layer, and the RESURF layer stack of the HV L-BJT **350** (or L-BJT **1600**) and the respective regions of the MOS transistor **280**.
Depletion Field Effect Potential Divider
[0331] As described above, with respect to FIGS. **4**A and **4**B, an inventive aspect relates to structures for dividing low voltage (5V or less) regions from voltage drop regions, e.g., in HV L-BJT **350** and HV MOS transistor **300**. By physically separating a collector region along which the potential drops from a voltage greater than 5 volts to a voltage equal or less than 5 volts, a broad range of voltages can be supported on a single chip that includes a first region on which LV MOS or LV BJT (e.g., L-BJT) devices are monolithically fabricated (e.g., co-fabricated or at least partially co-fabricated) and a second region in which a potential divider (PD) is fabricated. In some cases, the first and the second regions can be electrically isolated and the devices in the first region can be electrically connected to the PD via conductive lines comprising vertical sections connected to the PD and the devices receiving voltage from the PD, and lateral sections fabricated in metallization layers above the first and second regions, connecting the vertical sections. The PD can be a silicon based device and include features similar to the drift region extension of an HV L-BJT (e.g., HV L-BJTs **350**, **1600**). A PD may be designed to monotonic or substantially linearly scale a high voltage (e.g., a voltage greater than 5 volts, 10 volts, 50 volts, 80 volts, 100 volts, 200 volts, or greater) applied on an input port (or input node) to a low voltage (e.g., less than or equal to 5 volts) at an output port (or output node).
[0332] In some cases, the PD can be fabricated using the same low cost and fast cycle time bipolar-CMOS (BiCMOS) core process used for fabrication of LV MOS and BJT transistors. This approach has the advantage of enabling higher voltage signals to be monotonic or substantially linear scaled to the voltage node of any host process platform to enable a range of different design applications. Accordingly, superior analog signal translation between process platforms can be achieved.
[0333] In certain embodiments disclosed herein, the potential divider (PD) can be a semiconductor device configured to operate based on the principles of a depletion field effect (DFE). As such, the disclosed PD may be referred to as a depletion filed effect PD or DFE-PD. The DFE-PD monotonic or substantially linearly scales a higher input voltage at a first node (an input node) to a lower voltage at a second node (an output node). Thus, the DFE-PD is advantageous adapted for analog signal translation. In some embodiments, DFE-PD is a semiconductor device comprising a plurality of individually doped silicon regions (for example, four regions, or in certain implementations five or more regions) arranged to form a first semiconductor junction at the input node and a second semiconductor junctions at the output node. Upon biasing the DFE-PD (e.g., applying a voltage to

input node) according to embodiments, both the first and second junctions (e.g., PN junctions) can be reverse biased. When a voltage is applied to the input node a portion of the charge induced in the input node can be coupled from the first junction to the second junction generating an output potential in the output node thus serving as a potential divider (PD). A ratio of the voltage scaling can be defined by the ratio of charge coupled from the first junction to the second junction. By electrically connecting the DFE-PD in series with an LV BJT, an LV MOS transistor, or any suitable LV device, the voltage scaling operation can be electrically and physically separated from the a low voltage BiCMOS platform.

[0334] In certain implementations, the full extent of the voltage scaling can range from a direct one-to-one voltage translation to a situation in which the output voltage is independent of the input voltage and fixed to be substantially constant. In some embodiments, the construction and operation of a depletion field device can exist between two extreme operation regions or device classes. At one extreme, a punch-through device is provided where charge applied to a first depletion region of the first junction is directly coupled onto a second depletion region of the second junction such that the input voltage is substantially equal to the output voltage. At the other extreme, charge provided to the input node is substantially completely coupled onto one or more gate regions that shield the output node from any charge coupling from the input node. This results in a device having a substantially fixed output voltage that is relatively independent of an input voltage.

[0335] It is desirable to create a DFE-PD device that operates between these two extremes in order to monotonic or substantially linearly transform an input voltage signal into a scaled down output signal at least within an input voltage range (e.g., a voltage range having a lower bound of zero volt). To achieve this, an architecture similar to a junction field effect transistor (JFET) or a modified JFET structure can be used in which an inter-gate region has a shortened length, and a light doping concentration, and the same polarity as the gate regions (cf. an inter-gate region of a JFET, having a polarity opposite to the gate regions). In some cases, the inter-gate region on a DFE-PD electrically connects the gate regions.

[0336] In some cases, shortening the length of an inter-gate region eliminates voltage saturation at a pinch-off output voltage, and the reverse polarity and low doping concentration of the channel region (compared to a JFET) generates continuous voltage translation curve having a linear or substantially linear region and shifts a punch-through voltage of the device down (e.g., to zero voltage). In certain implementations, the length of the inter-gate region is balanced against the doping concentration such that the depletion regions of the input junction (first junction) and the depletion region of the output junction (the second junction) are coupled at zero input voltage. This results in a device that monotonically or substantially linearly translates an input voltage to a scaled down output voltage, where the magnitude of the scaling factor proportional by the ratio of the charge coupling. As such, the DFE-PD monotonically or substantially linearly scales an input voltage (V.sub.in) to a reduced output voltage (V.sub.out), where a scaling ratio (slope of the V.sub.in-V.sub.out curve) can be adjusted to a suitable value by carefully tailoring the length of the inter-gate region doping concentration.

[0337] FIG. **22**A schematically illustrates a cross-sectional view of a semiconductor device **2200** for voltage reduction with output saturation, and the corresponding voltage transfer function in an open ended output configuration. The semiconductor device **2200** can monotonically or substantially linearly scale an input voltage until the output voltage reaches saturation voltage (V.sub.p). In some cases, the semiconductor device **2200** can be configured to be similar to a JFET. The semiconductor device **2200** includes an LD channel region **2205** extended from an input region **2202** to an output region **2204** along a first lateral or longitudinal direction (e.g., along the x-axis), and two highly doped (HD) gate regions **2206***a*, **2206***b*, disposed on opposite sides of the LD channel region **2205** in a second lateral or transverse direction (e.g., y-axis) perpendicular to the longitudinal direction. The input region **2202**, the output region **2204**, and the channel region **2205**

have a same polarity opposite to a polarity of the gate regions **2206***a*, **2206***b*. For example, the gate regions **2206***a*, **2206***b* may comprise p-type semiconductors and the input region **2202**, the output region **2204**, and the channel region **2205** may comprise n-type semiconductor. The first gate region **2206***a* and the second gate region **2206***b* can have the same nominal potential (e.g., can be electrically shorted). The first and second gate regions **2206***a*, **2206***b* form PN-junctions **2208** with the channel region **2202**.

[0338] Carrier transport and E-field distribution in the inter-gate region of the channel region **2205** are controlled by the electrical characteristics of the gate regions **2206***a*, **2206***b* and a potential applied across these gate regions. The V.sub.in-V.sub.out plot **2209** shows the potential of the output region **2204** as a function of the potential of the input region **2202** for a given voltage difference between output region **2202** and the HD gate regions **2206***a*, **2206***b*, and when the output region **2204** is open ended (e.g., R.sub.LOAD>1MΩ). As V.sub.in is increased, V.sub.out increases monotonically or substantially linearly and a gap between the depletion regions **2208** becomes progressively smaller. At V.sub.in=V.sub.c the gap between the two depletion regions **2208** is closed and the electrical connection between the input regions **2202** and the output region **2204** is pinched off by the depletion regions, resulting in saturation and clamping of V.sub.out at V.sub.p (pinch-off voltage).

[0339] While the V.sub.in-V.sub.out behavior of the semiconductor device **2200** can be useful for reducing and limiting the voltage provided to a low voltage device, e.g., for protection from high voltage damage, for applications where a high voltage signal (e.g., a time varying signal) has to be controlled, processed by a circuit comprising LV devices, the saturation of the output voltage can distort the signal by chopping a portion of the signal having a voltage larger than a voltage (V.sub.c) at which V.sub.out becomes saturated. For such applications, the PD may be configured to monotonically or substantially linearly scale V.sub.in to V.sub.out with a scaling factor across a voltage range that is equal or larger than a peak voltage of the high voltage signal that should be processed by the LV device.

[0340] The monotonic or substantially linear scaling from V.sub.in to V.sub.out can be achieved by modifying the structure of the semiconductor device **2200**. As a first step, the length of the inter-gate region of the semiconductor device **2200** may be reduced to increase the slope of the saturated portion (V.sub.in>V.sub.c) of the V.sub.in-V.sub.out curve **2209** from zero to a positive value. FIG. **22**B schematically illustrates a cross-sectional view of another semiconductor device **2210** configured for voltage reduction, without output saturation, and the corresponding voltage transfer function (V.sub.in-V.sub.out curve) **2219** in an open ended output configuration. The structure of the semiconductor device **2210** can be arranged to the same as the structure of the semiconductor device **2210**, except for the length of the inter-gate region, which is reduced compared to that of the device **2200**, to allow for some charge coupling from the input region **2202** to the output region **2204** even when V.sub.in is larger than V.sub.out. In some cases, length of the inter-gate region of the semiconductor device **2200** can be from 3.0 to 10 microns. As shown in curve **2219**, when V.sub.out is smaller than V.sub.c, V.sub.out increases monotonically or substantially linearly with V.sub.in at a first slope and when V.sub.in is equal or larger than V.sub.c, V.sub.out increases linearly or substantially linearly with V.sub.in at a second slope smaller than the first slope. So because the inter-gate region is short even after pinch-off (V.sub.in>V.sub.c), a portion (ΔQ.sub.out) of the charge input to the inter-gate region (ΔQ.sub.in) is coupled to the output region **2204**. While at V.sub.in=V.sub.c the gap between the two depletion regions **2218** is closed, still some electrical connection between the input region **2202** and the output region **2204** can be supported by charge tunnelling through the pinched off region. Given the probability of charge tunnelling is proportional to the length of the inter-gate region, the second slope can be adjusted by adjusting the length of the inter-gate region.

[0341] As a second step toward substantially linearizing the V.sub.in-V.sub.out relation, the polarity of the inter-gate region of the semiconductor device **2210** can be configured to have the same

polarity as the polarity of the first and the second gate regions **2216***a*, **2216***b*, to electrically couple connect the first gate region **2216***a* to the second gate region **2216***b*, thereby effectively resulting in a pinch-off between the input region **2202** and the output region **2204** at V.sub.in=0. This can reduce or eliminates the first portion (V.sub.in<V.sub.c) of the V.sub.in-V.sub.out curve **2219** (FIG. **22**B).

[0342] FIG. **22**C schematically illustrates a cross-sectional view of another semiconductor device **2220** for monotonic or substantially linear voltage reduction with non-zero punch-through voltage (VPT≠0), and the corresponding voltage transfer function **2221** in an open ended output configuration. The inter-gate region **2213** of the semiconductor device **2220** has the first and the second gate regions **2216***a*, **2216***b* (e.g., they can be all p-type regions). Thus, the first and the second gate regions **2216***a*, **2216***b* are electrically connected and the charge coupling between the input region **2202** and the output region **2204** is pinched off at V.sub.in=0. However, due to formation of new depletion regions between the inter-gate region **2213** and the input and the output drift regions **2212**, **2214**, the electric charge cannot be coupled from the input region **2202** to the output region **2204** until V.sub.in is large enough to close a gap (e.g., the smallest gap along the longitudinal direction), between the two new depletion region boundaries **2228** and allow charge coupling through the inter gate region **2213** via a punch-through mechanism. As shown in the V.sub.in-V.sub.out plot **2221**, at a pinch-off voltage (V.sub.PT) **2222**, the charge is coupled through the inter-gate region **2213** and V.sub.out linearly or substantially linearly scales with V.sub.out similar to the second region (V.sub.in>V.sub.c) of the V.sub.in-V.sub.out plot **2219** (FIG. **22**B), and the slope of V.sub.in-V.sub.out line is primarily determined by the length of the inter-gate region.

[0343] The third step toward linearizing the V.sub.in-V.sub.out relation is to reduce a dopant concentration of the inter-gate region of the semiconductor device **2220** such that the gap between the two depletion region boundaries **2228** is eliminated or otherwise significantly reduced to allow charge coupling through the inter-gate region at V.sub.in=0 (or zero bias) via punch-through mechanism.

[0344] FIG. **22**D schematically illustrates a cross-sectional view of an example DFE-PD device **2240** that can monotonically or substantially linearly scale V.sub.in to V.sub.out, and the corresponding voltage transfer function **2241** in an open ended output configuration. The structure of the DFE-PD **2240** is identical to the structure of the semiconductor device **2220** (FIG. **22**C), except that the concentration of majority carriers in its inter-gate region **2215** is reduced (e.g., by reducing the doping concentration), compared to that of the device **2200**, to charge couple the input region **2202** to the output region **2204** even when V.sub.in is zero. As shown in the V.sub.in-V.sub.out plot **2241**, an input voltage (V.sub.in) applied to the input region **2202** of the DFE-PD **2240** may be linearly or substantially linearly scaled to an output voltage (V.sub.out) generated in its output region **2204** from V.sub.in=V.sub.out. Similar to the semiconductor device **2220** (FIG. **22**C), the V.sub.in-V.sub.out slope is primarily determined by the length of the inter-gate region **2215**. In some cases, a maximum voltage drop from the input region **2202** to the output region **2204** may be limited by the breakdown voltage of one of the junctions. In some cases, increasing the length (L.sub.D) of the as input drift region **2212** may increase the maximum input voltage that can be scaled down by the DFE-PD according to its V.sub.in-V.sub.out slope. In some cases, increasing the length (L.sub.O) of the output drift region **2214** may increase the maximum voltage that can be output by the DFE-PD.

[0345] FIGS. **23**A-**23**B schematically qualitatively illustrate the evolution of E-field and charge coupling through inter-gate region **2215** of an example DFE-PD **2300**, and the resulting voltage transformation. In the DFE-PD **2300**, input and output regions are eliminated and the input region **2202** and the output region **2204** are directly in contact with the inter-gate region **2215**. The concentration of the majority carrier in the inter-gate region **2215** and the length (L.sub.p) of the inter-gate region **2215** are adjusted such that the depletion region boundaries **2228** are in contact or separated by a small gap therebetween along the longitudinal direction (e.g., along x-axis), where

the gap can be smaller than 150 nanometer, 500 nanometer, 1000 nanometer, or a value in a range between any of these values. When an input voltage (V.sub.in) is applied between the input region **2202** and the first and second gate regions **2216***a*, **2216***b*, a first portion (ΔQ.sub.1) of the charge (ΔQ.sub.in) generated in the input region **2202** couples to the first and second gate regions **2216***a*, **2216***b* (that are at or substantially at equipotential), and a second portion (ΔQ.sub.2) of ΔQ.sub.in couples to the output region **2204**, resulting in an output voltage V.sub.out between the first and second gate regions **2216***a*, **2216***b*, at the output region **2204**. Accordingly, a first portion of the E-field associated with ΔQ.sub.in is coupled to the first and second gate regions **2216***a*, **2216***b* (that are at or substantially at equipotential), and a second portion of the E-field associated with ΔQ.sub.in is coupled to the output region **2204**, resulting in an output voltage V.sub.out between the first and second gate regions **2216***a*, **2216***b*, at the output region **2204**. As V.sub.in is increased, ΔQ.sub.1 and ΔQ.sub.2 increase proportionally to ΔQ.sub.in such that the ratio ΔQ.sub.2/ ΔQ.sub.in and the corresponding voltage ratio ΔV.sub.out/ΔV.sub.in stay constant or nearly constant. The E-fields couple to the first and second gate regions **2216***a*, **2216***b*, such that the output region **2204** change in the same manner as ΔQ.sub.1 and ΔQ.sub.2. As shown in the V.sub.in-V.sub.out plot **2309**, as V.sub.in is gradually increased from 0 volt, V.sub.out increases with a slope smaller than 45 degrees (indicating voltage reduction). The V.sub.in-V.sub.out shows that increasing the V.sub.in does not change the slope of the V.sub.in-V.sub.out indicating that the E-field coupling and charge coupling ratios are not significantly affected by the magnitude of V.sub.in. At low voltage regimes, a contact point between the depletion region boundaries **2228** (or a lateral position at which the gap between them is reduced or minimized) moves toward the output region **2204** and eventually the two boundaries merge near the output region **2204**.

[0346] While the configuration of the DFE-PD **2300** simplifies visualization of the evolution of E-field and charge coupling, at least qualitatively, the evolution of E-field and charge coupling in the inter-gate region of the DFE-PD **2240** (FIG. **22**D) will be similar to that of the DFE-PD **2300**.

[0347] FIGS. **24**A-**24**B schematically illustrate two DFE-PDs **2400**, **2410**, respectively, having inter-gate regions with different geometries. The DFE-PD **2400** has a short inter-gate region **2415***a* having a length (along x-axis) substantially smaller than a width (along y-axis). In the example shown, the length of the inter-gate region **2415***a* is sufficiently short such that nearly all the E-filed lines and the charge generated in the input region **2202** are coupled to the output region **2204**. As a result, the slope of the V.sub.in-V.sub.out line (in the plot **2411**) is near 45 degrees indicating that voltage scaling ratio is near 1 and the DFE-PD **2400** does not reduce the voltage. In some examples, the length of the inter-gate region **2415***a* can be than less than 5 microns, depending on, among other things, the doping concentrations of the input and output regions **2202**, **2204**, relatively to that of the inter-gate region **2415***a*.

[0348] DFE-PD **2410** has a long inter-gate region **2415***b* having a length (along x-axis) substantially greater than a width (along y-axis). In the example shown, the length of the inter-gate region **2415***a* is sufficiently long such that nearly all the E-field lines and the charge generated in the input region **2202** are coupled to the first and second gate regions **2216***a*, **2216***b*. As a result, the slope of the V.sub.in-V.sub.out line (in the plot **2412**) is near 0 degrees indicating that the DFE-PD **2410** generates a constant (near zero) V.sub.out independent of V.sub.in. In some examples, the length of the inter-gate region **2415***b* is longer than 5.0 microns but less than 20.0, depending on, among other things, the doping concentrations of the input and output regions **2202**, **2204**, relatively to that of the inter-gate region **2415***b*.

[0349] FIG. **25**A schematically illustrates a cross-sectional view of a DFE-PD **2500** with an extended drift region. Similar to DFE-PD **2240** (FIG. **22**D), DFE-PD **2500** comprises an input region **2202**, an output region **2204**, an inter-gate region **2215** extending in the longitudinal (e.g., x) direction from the first end to the second end, an input drift region **2212** extending from the input region **2202** to a first end of the inter-gate region **2215**, and an output drift region **2214** extending from the second end of the inter-gate region **2215** to the output region **2204**. The DFE-PD **2500**

further comprises a first and second gate regions **2216***a*, **2216***b*, disposed above and below the inter-gate region **2215** respectively. The inter-gate region **2215** is laterally bound by the first and second gate regions **2216***a*, **2216***b* that extend from the first end to the second end of the inter-gate region **2215**.

[0350] FIG. **25**B shows calculated voltage variation plotted against a longitudinal distance from the output region **2204** (where 0 corresponds to the location output region **2204**) of the DFE-PD **2500**, for eight different values of the input voltage (V.sub.in) including V.sub.in=40.5 volts (curve **2502**), V.sub.in-35.5 volts (curve **2504**), V.sub.in=30.5 volts (curve **2506**), V.sub.in=25.5 volts (curve **2508**), V.sub.in=20.5 volts (curve **2510**), V.sub.in=15.5 volts (curve **2512**), V.sub.in=10.5 volts (curve **2514**), V.sub.in=5.5 volts (curve **2516**). Voltage at the x-axis value of −21 microns corresponds to V.sub.in (left vertical axis) and the voltage at the x-axis value of 0 corresponds to V.sub.out (right vertical axis). As shown in the plot **2502**, the voltage is nearly constant along the input drift region **2212**, drops across the inter-gate region **2215** and is nearly constant along the output drift region **2214**. While the length (L.sub.p) of the input drift region **2212** and the length (L.sub.o) of the output drift region **2214** do not significantly contribute to the voltage drop along the DFE-PD **2500**, the maximum V.sub.in that can be applied to the input region **2202** and the maximum V.sub.out that can be output by DFE-PD **2500**, without causing damage to any junctions or oxide layers, can depend on L.sub.p and L.sub.o respectively. FIG. **26**A shows calculated V.sub.out plotted against V.sub.in, when V.sub.in varies from 0 to 40 volts for the DFE-PD **2500**. The V.sub.out-V.sub.in is not perfectly linear but an average voltage scaling factor (V.sub.out/V.sub.in) for this device is about 5. FIG. **26**B shows output current per unit length of the DFE-PD **2500** plotted against V.sub.in. In some cases, the linearity of the V.sub.out-V.sub.in transfer curve is controlled by the geometry and doping profile of the inter-gate region **2215** relative to the doping profiles of the input drift region **2212** and the output drift region **2214**. Optimizing those doping profiles and coupling geometry can improve the linearity. For calculating the curves shown in FIGS. **26**A and **26**B, box-shape doping profile have been used to simplify the calculations. Using, graded doping profiles (along x-axis, y-axis, or both) and carefully tailoring the doping profiles may improve the linearity V.sub.out-V.sub.in curve (e.g., extend the linear region to larger voltage ranges).

[0351] In some cases, increasing the length (L.sub.p) of the input drift region and the length (L.sub.o) of the output drift region and adding RESURF plates, herein referred to as “field plates,” above them may increase the maximum magnitude of the V.sub.in and V.sub.out that can be supported by a DFE-PD, respectively. These field plates can function similar to the field plates **1510***a*, **1510***b*, **1612**, **1618** above the drift region extension **304***b* of the HV L-BJTs **350**, **1600** (FIG. **16**). These field plates can keep a lateral component of the E-field in the input drift region **2212** and/or the output drift region **2214** substantially constant to cause a voltage drop along the input drift region **2212** and/or output drift region **2214**. FIG. **27**A schematically illustrates a side cross-sectional view of a DFE-PD **2700** with gate regions **2716***a*, **2716***b*, extending over the input drift region **2212**. The portion of the gate regions **2716***a*, **2716***b*, extended over the input drift region **2212** can function as field plates and cause a linear or substantially linear voltage drop **2702** along the input drift region **2212**. In some cases, the length (L.sub.resurf-1) of the portion of gate regions **2716***a*, **2716***b*, extending over the input drift region **2212** can be less than the length (LD) of the input drift region **2212**. In various implementations, a portion of the first gate region **2716***a* that extends over the input drift region **2212** may comprise one or more electrically connected field plates (e.g., metallic and/or polysilicon field plates) placed above each other and above the input drift region **2212**. These field plates can be connected to the portion of the gate region **2716***a* over the inter-gate region **2215**. Similar to the field plates **1510***a*, **1510***b*, **1612**, **1618** of the HV L-BJTs **350**, **1600**, a vertical distance between these filed plates and a top surface of the input drift region **2212** can increase from an interface between the integrate region **2215** toward the input region **2202**. In some examples, a portion of a well region or a substrate in which DFE-PD **2700** is formed

may be electrically connected to the first gate region (e.g., via an ohmic contact) and serve as the second gate region **2716***b* and one or more field plates.

[0352] In some cases, the largest input voltage magnitude that can be scaled down by the DFE-PD **2700** can be limited by a resulting reduced voltage that can damage the junctions and/or isolating dielectric layers near the interface between the inter-gate region **2215** or within the output region **2204** (e.g., 5 volts). By way of illustration, if the voltage scaling factor of a DFE-PD **2700** is 40, the upper limit for V.sub.in can be 200 volts because scaling down any voltage above 200 volts by a factor of 40 can generate a voltage above 5 volts near the interface between the inter-gate region **2215** or within the output region **2204** (e.g., 5 volts). In some embodiments, an upper limit for V.sub.out can be increased (e.g., above 5 volts), by extending the output drift region **2214** and providing one or move field plates above it. FIG. **27**B schematically illustrates a side cross-sectional view of a DFE-PD **2704** with gate regions **2717***a*, **2717***b*, extending over the output drift region **2214**. The portion of the gate regions **2717***a*, **2717***b*, extending over the output drift region **2214** can function as field plates and cause a linear or near linear voltage drop along the output drift region **2214**. In some cases, the length (L.sub.resurf-2) of the portion of gate regions **2717***a*, **2717***b*, extending over the output drift region **2214** can be less than the length (L.sub.o) of the output drift region **2214**. In various implementations, a portion of the first gate region **2717***a* that extends over the output drift region **2214**, may comprise one or more electrically connected field plates (e.g., metallic and/or polysilicon field plates) placed above each other and above the output drift region **2214**. These field plates can be connected to the portion of the first gate region **2717***a* over the integrate region **2215**. Similar to the field plates **1510***a*, **1510***b*, **1612**, **1618** of the HV L-BJT **350**, **1600** described above, a vertical distance between these filed plates and a top surface of the output drift region **2214** can increase from an interface between the integrate region **2215** toward the output region **2214**. In some examples, a portion of a well region or a substrate in which DFE-PD **2704** is formed may be electrically connected to the first gate region **2717***a* (e.g., via an ohmic contact) and serve as the second gate region **2717***b* and one or more field plates.

[0353] FIG. **28**A schematically illustrates a cross-sectional view of a practical implementation of an DFE-PD that can be fabricated to have input/output regions, gate regions and/or field plates at the same major surface of a substrate (e.g. a front side of a silicon substrate). The illustrated DVE-PD comprises HD regions (**2202**, **2808**, **2204**, and **2812**), and LD regions (**2212**, **2215**, **2214**) formed in a well **2828**. The DFE-PD **2800** may further comprise isolating dielectric layers (e.g., an isolating dielectric layer **2818**), and one or more field plates **2820** above the LD and HD regions. The process architecture of the DFE-PD **2800** is analogous to that of the DFE-PD **2700** (FIG. **27**A) having analogous electrical configuration of LD and HD regions, but a different physical geometry. The input drift region **2212** of the DFE-PD **2800** extends in a lateral direction (e.g., along x-axis) from an input region **2022**, to a first vertical interface with an inter-gate region **2215**. The inter-gate region **2215** is extended from the first vertical interface to a second interface with an output drift region **2214**. The first and second vertical interfaces electrically correspond to the first and second junctions and the resulting depletion regions **2228** of the DFE-PD **2700** (FIG. **27**A). The DFE-PD **2800** further comprises an output region **2204**, a first gate region **2808**, and a gate contact region **2812** that provides electrical contact to the well (second gate region) **2828**. A region of the well **2828** below the input drift region **2212**, the inter-gate region **2215**, and the output drift region **2214**, serve as the second gate region analogous to the second gate region **2717***b* of the DFE-PD **2704** described above with respect to FIG. **27**B.

[0354] In some cases, the input drift region **2212**, the inter-gate region **2215**, and the output drift region **2214** are doped regions formed in the well **2828** using suitable doping methods (e.g., thermal diffusion or implantation) used in MOS fabrication processes described herein. Similarly, the input region **2202**, the output region **2204**, the first gate region **2808**, and the gate contact region **2812** are formed in the input drift region **2212**, the inter-gate region **2215**, and the output drift region **2214**, respectively. In some cases, the input drift region **2212**, the inter-gate region

2215, and the output drift region **2214** are LD regions having a low doping concentration or a low majority carrier concentration (e.g., lower than HD regions). In some cases, the input region **2202**, the first gate region **2808**, the output region **2204**, and the gate contact region **2812** are HD regions having a high doping concentration or a high majority carrier concentration and can serve as ohmic contacts.

[0355] The input region **2202**, the input drift region **2212**, the output drift region **2214**, and the output region **2204** can have the same polarities. In some cases, a doping concentration or carrier concentration of the input region **2202** can be similar or substantially identical to that of the output region **2204**. In some cases, a doping concentration or carrier concentration of the input drift region **2212** can be similar or substantially identical to that of the output drift region **2214**.

[0356] The first gate region **2808**, the inter-gate region **2215**, and the gate contact **2812**, and the well **2828** can have the same dopant polarity type. In some cases, a doping concentration and/or majority carrier concentration of the first gate region **2808** can be identical to that of the gate contact **2812**.

[0357] Still referring to FIG. **28**A, the DFE-PD **2800** further includes a thick isolating dielectric layer **2818** (e.g., an oxide layer such as a LOCOS or STI layer) above the first drift region **2212**, and three field plates **2820** disposed above the thick isolating dielectric layer **2818**. The field plates **2820** may comprise a first field plate **2820***a* disposed on top of the thick isolating dielectric layer **2818**, a second field plate **2820***b* placed above the first field plate **2820***a* and extended in the lateral direction towards the input region **2202**, and a third field plate **2820***c* above the second field plate **2820***b* and extended in the lateral direction towards the input region **2202**. In some cases, the first, second, and third field plates **2820***a*, **2820***b*, **2820***c* may cover a portion (L.sub.resurf-1) of the length (L.sub.D) the input drift region **2212**. In some examples, L.sub.p can be larger than L.sub.resurf-1 by a factor of 1.2, 1.4, 1.6, 1.7, 2 or larger or smaller values.

[0358] In some cases, the arrangement of the first, second, and third field plates **2820***a*, **2820***b*, **2820***c* can be similar to that of the second, third, and fourth field plates **1510***a*, **1612**, **1618** described above with respect to the HV L-BJT **1600**. In some cases, the first, second, and third field plates **2820***a*, **2820***b*, **2820***c* may comprise features (e.g., geometrical and material characteristics) similar to those of the second, third, and fourth field plates **1510***a*, **1612**, **1618** respectively. For example, the first field plate **2820***a* may comprise polysilicon and the second and third field plates, **2820***b*, **2820***c*, may comprise a metal or metal alloy. Similar to the second, third, and fourth field plates **1510***a*, **1612**, **1618** of the HV L-BJT **1600**, the first, second, and third field plates **2820***a*, **2820***b*, **2820***c* can maintain at least a lateral component of the E-field in the input drift region **2212** constant or nearly constant, e.g., by introducing vertical E-field components (e.g., along y-axis) along the input drift region **2212**. As a result, the presence of the field plates may result in a voltage drop (ΔV.sub.drift) along the first drift region **2212** in addition to the voltage drop (ΔV.sub.dep) in the inter-gate region **2215**. The resulting voltage scaling factor of the DFE-PD **2800** can be larger than that of the DFE-PD **2500** (FIG. **25**A).

[0359] In various implementations, the ΔV.sub.drift can be adjusted by changing the length (L.sub.D) of the input drift region **2212** and the ΔV.sub.dep can be adjusted by changing the length (L.sub.p) of the inter-gate region **2808**, and majority carrier concentration (or doping concentration) in the inter-gate region **2808**. In various implementations ΔV.sub.dep can be from 0 to 5 volts, and ΔV.sub.drift can be from 0 to 300 volts.

[0360] In various implementations, L.sub.p can be from 0.1 to 5.0 microns, L.sub.p can be from 0.5 to 25 microns, majority carrier concentration (or doping concentration) in the inter-gate region **2808** can be from 10.sup.15 to 10.sup.17 cm.sup.−3. In some examples, the majority carrier concentration (or doping concentration) in the inter-gate region **2808** is lower than those of the first gate region **2808** and well (the second gate region) **2828**. In some implementations, a difference between the majority carrier concentration (or doping concentration) in the inter-gate region **2808** and the first gate region **2808** can be from 10.sup.16 to 10.sup.17 cm.sup.3. In some examples, a

difference between the majority carrier concentration (or doping concentration) in the inter-gate region **2808** and the well (the second gate region) **2828** can be from 10.sup.16 to 10.sup.17 cm.sup. −3.

[0361] In some cases, the field plates **2820** and the gate contact **2812** may be substantially at equipotential. For example, they can be connected to an ohmic region or electrode having a stable and constant potential (e.g., a ground plane), during the operation of the DFE-PD **2800**.

[0362] The plot **2802** shows calculated variation of voltage in a lateral direction (e.g., along x-axis) along the DFE-PD **2800**, plotted against a distance from the input region **2202** for four different values of the input voltage (V.sub.in) including V.sub.in=200 volts (curve **2830**), V.sub.in=144 volts (curve **2832**), V.sub.in=100 volts (curve **2834**), and V.sub.in=2836 volts (curve **2836**). The plot **2803** is a close-up view of a portion of the plot **2802** near the interface between the inter-gate region **2215** and within the output region **2204**.

[0363] In some implementations, fabrication of the DFE-PD **2800** may comprise forming the doped substrate region **2828** by implanting a top layer of a silicon-on-insulator (SOI) wafer and thermally driving down dopant below toward the buried oxide layer **1904**. Next, an epitaxial layer is grown on top of the silicon layer and single well would be implanted for the entire length extending from regions **2214** to **2212**. Next, a second well of opposite dopant is implanted to form the inter-gate region **2215**. In some cases, the dopant concentration of this well would exceed the dopant of well regions **2214** and **2212**. These wells would be thermally driven until they merge with the buried dopant layer **2828**. The excessive dopant of **2215** would counter dope **2214** and **2212** to form a more lightly net doped region **2215**. Next, the dielectric layers are formed and the heavily doped regions (ohmic contacts), **2202**, **2208**, **2204**, and **2812** are be implanted. Finally, the metallic interconnects are formed.

[0364] FIG. **28**B shows an example calculation of V.sub.out plotted against V.sub.in, when V.sub.in varies from 0 to 200 volts for DFE-PD **2800**. The V.sub.out-V.sub.in is not perfectly linear but an average voltage scaling factor (V.sub.out/V.sub.in) for this device is about 40. FIG. **28**C shows an example calculation of the output current per unit length of the DFE-PD **2800** plotted against V.sub.in.

[0365] FIG. **28**D schematically illustrates snapshots of the depletion regions of the DFE-PD **2800** at five different magnitudes of bias or input voltages (e.g., voltages applied between the input region **2202** and the first gate region **2808**). Associated with every junction are two depletion boundaries that push into either side of the opposing junction dopant. In FIG. **28**D, the depletion boundaries **2820***a*-**2820***e* and **2824***a*-**2824***e* represent one side of eth depletion regions of two junctions. The depletion region on the other side of the junctions in the inter-gate region are merged. In some cases, the depletion boundaries represented by **2822***a*-**2822***e* show how the merged depletions within inter-gate cannot merge around the higher doped regions.

[0366] As mentioned above, in some applications, a high input voltage can be scaled down to a lower voltage, but can still be too high for junctions and dielectric layers near the interface between the inter-gate region **2215** or within the output region **2204** (e.g., 5 volts). For example, a region or a device in an IC may be designed to operate at 50 volts, while an available source may generate an output voltage of 200 volts (a voltage scaling factor of 4). While by reducing L.sub.p and/or L.sub.D the voltage scaling factor of DFE-PD **2800** can be reduced to 4, the output region **2204** may be damaged by the resulting scaled down voltage (50 volts). This limitation can be removed by employing a longer output drift region **2204** and adding one or more field plates (RESURF plates) above the output drift region **2204** (the same design used for the input drift region **2212**).

[0367] FIG. **29** schematically illustrates a cross-sectional view of a DFE-PD **2900** having an extended output region **2914** and two field plates **2944**, **2942** placed above the extended output region **2914**. In some examples, the input region, the output drift region, the dielectric layer on the input region, the inter-gate layer, the gate layer, of and the DFE-PD **2900** and the well in which DFE-PD **2900** is formed be analogous to the corresponding features of the DFE-PD **2800**.

[0368] Unlike the DFE-PD **2800**, the DFE-PD **2900** comprises an extended output region **2914**, and a thick dielectric layer **2940** disposed thereover. In some cases, the field plates **2944**, **2942** may cover a portion (L.sub.resurf-2) of the length (L.sub.o) of the extended output drift region **2914**. In some examples, L.sub.o can be larger than L.sub.resurf-2 by a factor of 1.2, 1.4, 1.6, 1.7, 2 or have a value in range defined by any of these values or larger or smaller values. The extended output region **2914** and the field plates **2944**, **2942**, may allow the DFE-PD **2900** to support output voltages above 5 volts. An upper limit for the magnitude of the output voltage for DFE-PD **2900** may be increased by increasing L.sub.o and L.sub.resurf-2.
[0369] In some cases, the field plates **2944**, **2942** and the gate contact **2812** may substantially be at equipotential. For example, they can be connected to an ohmic region or an electrode having a stable and constant potential (e.g., a ground plane), during the operation of the DFE-PD **2900**.
[0370] The thick dielectric layers **2818** and **2940** may comprise one or more features described above with respect to the thick dielectric layer **1614** of the HV L-BJT **350** (FIGS. **16**A, **16**B).
[0371] To support a voltage drop (e.g., a substantially linear voltage drop) along the input drift region **2112** and/or the output drift region **2214**, more field plates may be added above each drift region. A vertical distance of each field plate from the top surface of the corresponding drift region can be smaller than that of a subsequent field plate. The length of each field plate and its relative vertical distance with a respect to adjacent field plates may be determined based on input voltage or voltage range to the PD and a desired output voltage or voltage range provided by the PD.
[0372] In some embodiments, the DFE-PD **2800** or the DFE-PD **2900** can be isolated in the lateral direction using deep trenches **1902** filled with a dielectric material (e.g., an oxide). These deep trenches may be extended from the isolating dielectric layers **218** to a buried dielectric layer **1904** that vertically isolates (electrically) an upper region of a substrate on which the well **2828** is formed (e.g., below the well **2828**), from a lower region of the substrate.
MOS Devices Coupled with High Voltage Potential Divider
[0373] As discussed above, another second inventive aspect allows the low voltage BiCMOS platform to be elevated to a higher voltage node using a high voltage potential divider that is connected in series with the lower voltage devices to create high voltage devices.
[0374] In some embodiments the DFE-PDs described above can be electrically connected (e.g., in series) to a low or medium voltage bipolar junction device (e.g., an L-BJT), or a low voltage MOS device (e.g., a MOSFET). In some cases, DFE-PDs, the bipolar devices, and the MOS devices can be fabricated on a common substrate using MOS fabrication techniques and libraries similar to those described above. In some such cases, at least a portion of a DFE-PD can be co-fabricated with a bipolar and/or MOS device. The DFE-PDs can be laterally separated or isolated from the bipolar devices, and the MOS devices, and/or vertically separated or isolated from the common substrate.
[0375] In some cases, the DFE-PDs can be fabricated on integrated circuit (IC) comprising bipolar junction devices and MOS devices. In some cases, the DFE-PDs can be fabricated on a high-voltage region of the IC that is electrically isolated from a low-voltage region of the IC (e.g., by deep dielectric filled trenches). In some examples, the DFE-PDs can be connected to the devices in the low voltage regions via vertical conductive lines (vias) connected to a common lateral conductive line fabricated, e.g., in a metallization layer of the IC above the substrate. In some embodiments, a DFE-PD may be electrically connected to a multiple low voltage devices that receive a reduced voltage from the DFE-PD. In various implementations, the DFE-PD may have a voltage scaling factor of 2 to 5, 5 to 10, 10 to 20, 20 to 30, 30 to 40, 40 to 50, or a value in a range defined by any of these values or larger values. The DFE-PD may be configured to scale down a high voltage level to a voltage level safe for a low voltage device (e.g., equal or less than 5 volts), or a medium voltage device (e.g., equal or less than 80 volts).
[0376] In some embodiments, the DFE-PD and a low voltage device (e.g., an L-BJT or a MOS transistor) may have at least one layer having a common material or physical dimension, or at least

one doped region having a common doping profile.
[0377] The input region, output region and the drift regions of a DFE-PD may have the same polarity as the drain region of a MOS transistor or a collector region of an L-BJT to which it is connected.
[0378] In a similar manner to the synergistic processing advantages of HV L-BJTs described above, various synergistic parallel processing of DFE-PDs with L-BJTs and MOS transistors can be performed, including definition of one or more of respectively thick dielectric layers, field plates, extended drift regions, and HD and LD doped regions. The details of the synergistic processing have been described above, and the details are not repeated herein for brevity.
[0379] In some cases, a DFE-PD and a low voltage (LV) MOS transistor that receives a reduced voltage from the DFE-PD can electrically behave similar to a single HV MOS transistor, e.g., a LDMOS transistor. A channel region of such LDMOS transistor can be laterally interposed between the HD input region **2202** of the DFE-PD serving as a drain of eth LDMOS and the HD source region of the LV MOS having the same polarity as the HD input region **2202**. The HD output region **2204** of the DFE-PD is physically separated by the inter-gate structure from, while being electrically connected to, the HD drain region of the LV MOS. The LDMOS transistor may further comprises a backgate contact electrically connected to the field plate **2820** formed over the extended input drift region serving as a reduced surface field (RESURF) plate. The LDMOS transistor may comprise a backgate contact electrically connected to the gate region **2802** of the DFE-PD.
[0380] FIG. **30**A schematically illustrates a cross-sectional view of a DFE-PD **2800** laterally isolated and/or separated from and electrically connected to a lateral BJT similar to, e.g., the L-BJT **240** described above (FIG. **2**). The output region **2204** of the DFE-PD **2800** is connected to the HD collector region **707** of the L-BJT **240** via a first conductive line **3000**. The conductive line **3002** can be a conductive line patterned in a metallization layer above a substrate on which the DFE-PD **2800** and L-BJT **240** are fabricated and the output region **2204** and the HD collector region **707** can be electrically connected to the first conductive line **3000** through two individual vertical conductive lines (vias).
[0381] The first gate region **2808**, field plates **2820** and the gate contact **2812** of the DFE-PD **2800** are connected to the RESURF contact **712***b* and the RESURF layer **714***b* of the L-BJT **240** via a second conductive line **3002**. The second conductive line **3002** can be a conductive line in a metallization layer above a substrate on which the DFE-PD **2800** and L-BJT **240** are fabricated and the first gate region **2808**, field plates **2820**, the gate contact **2812**, and the RESURF contact **712***b* can be electrically connected to the second conductive line **3002** through two individual vertical conductive lines (e.g., vias). In various embodiments, the first and the second conductive lines **3000**, **3002** can be fabricated on the same or different metallization layers.
[0382] FIG. **30**B schematically illustrates a side cross-sectional view of a DFE-PD **2800** laterally isolated and/or separated from and electrically connected to a low voltage MOS transistor similar to, e.g., the MOS transistor **280** described above (FIG. **2**). The output region **2204** of the DFE-PD **2800** is connected to the HD drain region **721** of the MOS transistor **280** via a third conductive line **3004**. The third conductive line **3004** can be a conductive line patterned in a metallization layer above a substrate on which the DFE-PD **2800** and the MOS transistor **280** are fabricated, and the output region **2204** and the HD drain region **721** can be electrically connected to the third conductive line **3004** through two individual vertical conductive lines (e.g., vias).
[0383] The first gate region **2808**, field plates **2820** and the gate contact **2812** of the DFE-PD **2800** are connected to the gate contact **712***a* and the gate layer **714***b* of the MOS transistor **280** via a fourth conductive line **3006**. The fourth conductive line **3006** can be a conductive line patterned in a metallization layer above a substrate on which the DFE-PD **2800** and the MOS transistor **280** are fabricated and the first gate region **2808**, field plates **2820**, the gate contact **2812**, and the gate contact **712***a* can be electrically connected to the fourth conductive line **3006** through two

individual vertical conductive lines (e.g., vias). In various embodiments, the first, second, third and fourth conductive lines **3000**, **3002**, **3004**, **3006** can be fabricated on the same or different metallization layers.

[0384] In some cases, one or both of the MOS transistor **280** and the L-BJT **240** can be fabricated on a common substrate with the DFE-PD **2800**. For example, the MOS transistor **280** and the L-BJT **240** can be fabricated on a low voltage region of an IC that is electrically isolated from a high voltage region of the IC, on which the DFE-PD **2800** is fabricated. As shown in FIGS. **30**A-**30**B, in some cases, the electrical isolation can be provided by deep dielectric filled trenches disposed between a low voltage device (e.g., the MOS transistor **280**, the L-BJT **240**) and the DFE-PD **2800** and/or between the low and high voltage regions of the IC.

[0385] In some cases, the HD gate region **721**, the HD source region of the MOS transistor **280**, and collector region **707** of the L-BJT **240**, can be co-fabricated with output regions **2202**, **2204** of the DFE-PD **2800**.

High Voltage Devices Including Potential Divider Physically Separated from Low Voltage Devices

[0386] In some embodiments, a DFE-PD (e.g., DFE-PDs **2900** (FIG. **29**) or **2800** (FIG. **28**A)) described above, may be physically separated and/or electrically isolated from one or more low or medium voltage devices that that receive a scaled down voltage from the DFE-PD to avoid any damage to the low or medium voltage device by a high voltage signal. In various embodiments, the physical and/or electrical isolation may comprise lateral and/or vertical separation from the low or medium voltage devices via one or more dielectric layers. In some cases, lateral isolation may comprise isolation by a shallow or deep dielectric filled trench formed in the substrate or an oxide layer thermally grown (e.g., LOCOS) on a top (major) surface of the substrate. In some cases, the vertical isolation may be provided by a buried oxide layer, e.g., of a silicon-on-insulator substrate. In some other cases, the vertical isolation may be provided by a thick dielectric layer formed on or over the substrate (e.g., thermally grown or deposited oxide layer), and/or by a portion of one or more interlayer dielectric layers (ILDs) or intermetal dielectric layers (IMDs) deposited above the substrate. In some cases, the cladding layer **224** may comprise one of more ILD or IMD layers.

[0387] FIG. **31** schematically illustrates a cross-sectional view of an example high voltage device including electrical connections between the DFE-PD **2800** and a low voltage device such as the LV L-BJT **804**, fabricated on a common substrate, for controlling (e.g., switching, modulation, and the like) high voltage signals provided to the DFE-PD **2800** using the low voltage device, e.g., the LV L-BJT **804**. The DFE-PD **2800** and L-BJT **804***e* are laterally separated or isolated from each other using a deep dielectric filled trench **1902** and a buried dielectric layer **1904**. In some cases, the substrate may comprise a silicon-on-insulator (SOI) wafer where DFE-PD **2800** and the LV L-BJT **804** are fabricated on the top silicon layer above the insulating layer (e.g., a buried oxide layer of a silicon-on-insulator (SOI) substrate). The buried dielectric layer **1904** can provide advantages including, e.g., enabling reduction of the depth of the trench **1904** by blocking carrier flow between the two devices through an unblocked region of the substrate below the trench **1902**. As shown in FIG. **31**, similar dielectric trenches may be used to electrically isolate the DFE-PD **2800** and LV L-BJT **804** from other devices fabricated on the common substrate. The deep trenches **1902** may extend from the isolating dielectric layers **218** to the buried dielectric layer **1904**. In some cases, the deep trenches **1902** may in contact with the buried dielectric layer **1904**. In some cases, a vertical gap between a deep trench **1902** and the buried dielectric layer **1904** can be less than 50 nm, or less than 10 nm.

[0388] The output region **2204** and the HD collector region **707** of the LV BJT **804** are electrically connected via a first conductive line **3000** fabricated in a metallization layer connected above the top surface of the common substrate. The field plates **2820**, the first gate region **2808**, the gate contact region **2812**, and the RESURF layer **714***b* are electrically connected via a second conductive line **3002** fabricated in a metallization layer above the top surface of the common substrate. The first and the second conductive lines **3000**, **3002** can be fabricated on the same or

different metallization layers.
[0389] In various implementations, the inter-gate region of an DFE-PD can control a coupling ratio between an input voltage and the corresponding output voltage in two configurations; the first configuration, described above includes one or more interfaces or junctions with a HD gate region on top or bottom, or both sides of the inter-gate region and electric field coupling to these gate regions controls the voltage drop across the inter-gate region. In a second configuration, the DFE-PD may control the voltage drop across the inter-gate region based on electric field coupling to one or more adjacent HD regions of electrodes that are not in contact with the inter-gate region. The electric field coupling to such electrically isolated HD regions or electrodes may have the same effect as the HD gate regions **2216***a* and **2216***b*, on voltage drop across the inter-gate region and controlling the ratio between the input and output voltages.
[0390] In some embodiments, the architecture of the DFE-PD **2800** can be modified by removing one or both of the gate regions **2216***a*, **2216***b* and relying on the dynamics of the depletion region boundaries **2228** for voltage scaling. In some cases, the second gate region **2216***b* may be eliminated and first gate region **2216***a* may be separated from the inter-gate region **2215**. In these examples, the region where the dielectric regions reside, also referred to herein to as the inter-gate region **2215**, may be referred to as a depletion control region.
[0391] FIG. **32** schematically illustrates a cross-sectional view of an example high voltage device including electrical connections between a DFE-PD **3206** and an L-BJT **3208**, fabricated on a common substrate, where the DFE-PD **3206** and L-BJT **3208** (that is similar to the L-BJT **800**) are laterally separated or isolated from each other by a dielectric layer **218**, and vertically separated or isolated from a lower region of the common substrate by a buried dielectric layer **909**. The dielectric layer **218** can be a shallow dielectric field trench (e.g., shallow trench oxide), or thermally grown oxide layer. In some examples, the buried dielectric layer **909** may be in contact or merged with the dielectric layer **218**. In some cases, a thickness of the dielectric layer **218** in the vertical direction can be from 0.3 to 0.5 microns. In some examples, a vertical gap or distance (e.g., along z-axis) between a bottom surface of the dielectric layer **218** and a top surface of the buried dielectric layer **909** can be less than 5 nm, or less than 10 nm. The DFE-PD **3206** may comprise an input region **2202**, an input drift region **3212**, a depletion control region **3220**, and an output region **2204**. The polarity and relative majority carrier concentrations (or doping concentrations) in these regions may be similar to those of the input region **2202**, the input drift region **2212**, the inter-gate region **2215**, and the output region **2204** region of the DFE-PD **2800** (FIG. **28**A), respectively. The DFE-PD **3206** may further comprise a thin dielectric layer **3203** above the depletion control region **3220**, a first field plate layer **2820***a*, spacers **3204** formed on the side walls of the first field plate **2820***a*, a second field plate **2820***b* above the first field plate **2820***a*, and a third field plate **2820***c* above the second field plate **2820***b*. The input drift region **3212** is bound in the vertical direction by one or more intermetal dielectric layers **224**, and the top surface of the buried dielectric layer **909**. In some embodiments, the DFE-PD **3206** may not include a thick isolating dielectric layer above its input drift region **3212**. In some cases, the second field plate **2820***b* may be connected to the first field plate **2820***a* through a vertical connector, e.g., a via, and extend in the lateral direction from a first end approximately aligned with a middle point of the first field plate **2820***a* to a second end above the input drift region **3212**. The third field plate **2820***c* may be connected to the second field plate through a vertical connector, e.g., via and extend in the lateral direction from a region near the second end of the second field plate **2820***b*. The field plates **2820** of the DFE-PD **3206** are configured to maintain a magnitude of the lateral E-field component in the input drift region **33212** relatively or nearly constant from input region **2202** to the output region **2204**. The output region **2204** and the HD collector region **207** of the LV BJT **3208** are electrically connected via a first conductive line **3000** fabricated in a metallization layer above the top surface of the common substrate. The field plates **2820** are electrically connected to the RESURF layer **714***b* via a second conductive line **3002** fabricated in a metallization layer above the top surface of the common

substrate. The first and the second conductive lines **3000**, **3002** can be fabricated as part of the same or different metallization layers.

[0392] FIG. **33** schematically illustrates a cross-sectional view of an example high voltage device including a DFE-PD that is vertically separated from the substrate and directly connected to an L-BJT. The device **3300** includes a DFE-PD **3320** that is directly connected to the L-BJT **730** while being vertically raised or separated from a substrate on which the L-BJT **730** is fabricated. The DFE-PD **3320** and L-BJT **730** are fabricated on a common substrate, thereby forming an integrated device effectively functioning as a HV L-BJT. The DFE-PD **3320** includes an input region **2202**, an input drift region **3312**, and a depletion control region **3220** that are disposed on a top surface of a thick dielectric layer **3304** disposed on the common substrate. In some cases, advantageously, the input region **2202**, the input drift region **3312**, and the depletion control region **3220** may be formed from the same layer, e.g., a polysilicon layer. In these embodiments, the thicknesses of these layers along the vertical direction (along y-axis), can be substantially equal. In some other cases, the base layer, e.g., a polysilicon layer, from which the input region **2202**, the input drift region **3312**, and the depletion control region **3220** may be formed may be co-deposited and co-patterned to have the same thickness with the RESURF layer **1510**, such that the thicknesses of all of these regions, along the vertical direction, are substantially equal. Furthermore, in some cases, one or more of the input region **2202**, the input drift region **3312** and the depletion control region **3220** may be co-doped to have the same dopant type and/or concentration as the RESURF layer **1510**. In various embodiments, the thicknesses of the input region **2202**, the input drift region **3312**, and the depletion control region **3220**, can be from 0.15 to 0.5 μm.

[0393] The DFE-PD **3320** includes an output drift region **2214** and an output region **2204**. The input drift region **3312** extends in the lateral direction from the input region **2202** to the depletion control region **3220**. The output drift region extends from the depletion control region **3220** to the output region **2204**. The output region **2204** is formed on or partially formed in a first substrate region **3302**. The first region of the substrate **3302**, the output region **2204**, the input drift region **3312** and the input region **2202** of the DFE-PD **3320**, and the emitter region **206** of the L-BJT **730** can have the same polarity opposite to a polarity of the depletion control region **3220** of the DFE-PD **3320** and the base region **208** L-BJT **730**. The output region **2204** of the DFE-PD **3320** can be laterally extended from the thick dielectric layer **3304** and a thick dielectric layer **734***b* that disposed over the drift region of the L-BJT **730**. In some examples, the output region **2204** of the DFE-PD **3320** may serve as the HD collector region of the L-BJT **730**. As such, the output region **2204** serves as a common electrical contact between the DFE-PD **3320** and L-BJT **730** arranged in electrical series. In some cases, the combination of DFE-PD **3320** and L-BJT **730** (the device within the dashed box **3340**) may electrically behave as an HV L-BJT with the input region **2202** serving as an effective collector region of the HV L-BJT.

[0394] The DFE-PD **3320** may further include two electrically connected field plates **2820***b*, **2820***c* over the input drift region **3312**, extending from an interface between the input drift region **3312** and the depletion control region **3220** toward the input region **2202**. Each field of the plates **2820***b*, **2820***c* can be fabricate as part of a different metallization layer, where a vertical distance of the field plate **2820** that is closer to the depletion control region **3220** from a top surface of the input drift region **3312** is smaller than that of the other field plate that is closer to the input region **2202**.

[0395] The common substrate may include a second substrate region **214** having a polarity opposite to a polarity of the first substrate region **3302**. The base well **208** of the L-BJT **730** may have portions formed in each of the first and second substrate regions **3302** and **214** and extend across a boundary therebetween.

[0396] In some cases, the first substrate region **3302** below the thick dielectric layer **3304** serves as a bottom field plate for the DFE-PD **3320** and contributes in maintaining the lateral component of the E-field within the input drift region **3312** relatively constant or near constant (a condition that results in monotonic or substantially linear reduction of voltage along the input drift region **3312**).

[0397] The field plates **2820***b*, **2820***c* and the RESURF layer **1510***b* can be electrically connected via conductive line **3002** fabricated in a metallization layer above the top surface of the common substrate. The conductive lines **3002** may be fabricated on the same metallization layer on which the field plate **2820***b* or field plate **2820***c* is fabricated, or on a different metallization layer.
[0398] Referring to the voltage versus distance curve shown at the lower half of FIG. **33**, when an input voltage (V.sub.in) is provided to the DFE-PD **3320**, the voltage variation along the device may have a piecewise behavior, and the voltage versus distance curve may include substantially constant segments **3310***a* and **3310***d*, and drop segments **3310***b*, **3310***c* and **3310***e*. For example, the voltage may remain constant or nearly constant within the segment **3310***a* along the input region **2202**, drop (e.g., monotonically or substantially linearly) within the segment **3310***b* along the input drift region **3312**, drop (e.g., monotonically or substantially linearly) within the segment **3310***c* with the same or different slope as the segment **3310***b* along the depletion control region **3220**, remain constant or nearly constant within the segment **3310***d* along the output region **2204** and along a first portion of a drift region of the L-BJT **730**, drop (e.g., monotonically or substantially linearly) within the segment **3310***e* along a second portion of the drift region below the RESURF layer **1510**, and remain constant **3310***e* along the base region of the L-BJT **730**. As such, the voltage drops from an input voltage (V.sub.in) level applied to the input region **2202** to an intermediate voltage (V.sub.Mid) along a first portion of the drift region, and from the intermediate voltage to a final voltage (V.sub.Fin) along the second portion of the drift region. In some cases, V.sub.Fin can be equal or less than 5 volts. In some cases, the ratio between the intermediate voltage and the input voltage (V.sub.Mid/V.sub.in) can be less than 50%, less than 40%, less than 30%, less than 20%, or less than 10%. In some cases, the slopes of the voltage drop segments **3310***b*, **3310***c*, **3310***e*, may be different and individually tailored by adjusting a length of the input drift region **3312**, a length and/or doping of the depletion control region **3220**, and a length of drift region of the L-BJT **730**, respectively.
[0399] FIG. **34** schematically illustrates a cross-sectional view of an example high voltage device including a DFE-PD that is vertically separated from the substrate and is electrically connected to an L-BJT via conductive lines. The device **3400** includes a DFE-PD **3420** that is electrically connected to an LV L-BJT **3410** while being vertically isolated and/or separated from a substrate on which the LV L-**3410** is fabricated. The DFE-PD **3420** and LV L-BJT **3410** are fabricated on a common substrate **290**, thereby forming the integrated device **3400** that effectively functions as an HV L-BJT. The DFE-PD **3420** includes an input region **2202**, an input drift region **3312**, a depletion control region **3220**, an output drift region **2204**, and an output region **2204** that are disposed on a top surface of a thick dielectric layer **3304** disposed on the common substrate **290**. The input drift region **3312** extends in the lateral direction from the input region **2202** to the depletion control region **3220**, and the output drift region **2214** is laterally extended from the depletion control region **3220** to the output region **2204**.
[0400] The DFE-PD **3420** may further include two electrically connected field plates **2820***b*, **2820***c* over the input drift region **3312**, extended from an interface between the input drift region **3312** and depletion control region **3220** toward the input region **2202**. Each field of the plates **2820***b*, **2820***c* can be patterned on a different metallization layer where a vertical distance of the field plate **2820** that is closer to the depletion control region **3220** from a top surface of the input drift region **3312** is smaller than that of the other field plate that is closer to the input region **2202**.
[0401] The output region **2204** of the DFE-PD **3420** and the HD collector region of the LV L-BJT **3410** can be electrically connected via a first conductive line **3000** fabricated in a metallization layer above the top surface of the common substrate. The RESURF layer **714***b* of the LVL-BJT **3410** can be electrically connected to the field plate **2820***b* via a second conductive line **3002** fabricated in a metallization layer above the top surface of the common substrate. The first and the second conductive lines **3000**, **3002** can be fabricated on the same or different metallization layers.
[0402] In some cases, the DFE-PD **3320** and L-BJT **730** may be fabricated in a well **3402** formed

in the common substrate **290**. The well **3402**, the input region **2202**, the output region **2204**, the input drift region **3312**, the HD collector region **207**, and the emitter region **206** may have the same polarity that is opposite to a polarity of the base well **208** and the depletion control region **3220**. In some cases, the majority carrier concentration in the depletion control region **3220** can be smaller than that of the input and put drift regions **3312**, **2214**.

[0403] In some cases, the combination of DFE-PD **3320** and L-BJT **730** (the device within the dashed box **3440**) may electrically behave as an HV L-BJT with the input region **2202** serving as the effective collector region of the HV L-BJT.

[0404] FIG. **35** schematically illustrates a cross-sectional view of an example high voltage device including a DFE-PD that is laterally and vertically separated and/or isolated from the substrate and is electrically connected to an L-BJT via conductive lines. The device includes a DFE-PD **3520** that is laterally and vertically separated and/or isolated from the substrate and is electrically connected to the LV L-BJT **804** via conductive lines. The DFE-PD **3520** may comprise one or more features described above with respect to DFE-PD **3420**. In some examples, the dielectric layer **3304**, the input and output regions **2202**, **2204** and the regions between them, and the field plates **2820***b*, **2820***c* can be analogous and similar to those of the DFE-PD **3420**. In the device in FIG. **35**, however, a first substrate region **3302** below the dielectric layer **3304** (on which the DFE-PD **3520** is formed) may include a gate contact **2812** (an HD region or ohmic contact) that allows the first substrate region **3302** to be electrically connected to the field plates **2820***b*, **2820***c* and thereby serve as a bottom field plate as part of the RESURF mechanism for the DFE-PD **3520**. The L-BJT **804** may have portions formed in each of the second and third substrate regions **204**, **202**, e.g., well regions that are doped oppositely, and extend across a boundary therebetween, where the second substrate region **204** forms a first vertical interface with the first substrate region **3302**. A dielectric layer **218** disposed above the first interface electrically isolates the gate contact **2812** of the DFE-PD **3520** from the HD collector region **207** of the LV L-BJT **804**. The second substrate region **204** may form a second vertical interface with the third substrate region **202**. In some cases, the third substrate interface can be aligned with an edge of the base region of the LV L-BJT **804**.

[0405] The output region **2204** of the DFE-PD **3520** and the HD collector region of the LV L-BJT **804** can be electrically connected via a first conductive line **3000** fabricated in a metallization layer above the top surface of the common substrate. The field plates **2820***b*, **2820***c*, the gate contact **2812**, and the RESURF layer **207** can be electrically connected via a second conductive line **3002** fabricated in a metallization layer above the top surface of the common substrate. The conductive lines **3002**, **3000** may be patterned as part of the same or different metallization layers.

[0406] Advantageously, as a result of the electrical connection between the first substrate region **3302** and the field plates **2820***b*, **2820***c*, the first substrate region **3302** serves as a bottom field plate and contributes to the RESURF mechanism of the DFE-PD **3520**.

[0407] In some embodiments, the input and output regions **2202**, **2204**, the input and output drift regions **3312**, **2214**, and the second substrate region **204** can have the same polarity that is opposite to a polarity of the first and the third substrate regions **3302**, **202**, and the depletion control region **3220**.

[0408] In some cases, the first, second, and the third substrate regions **3302**, **204**, **202** can be doped wells formed in the common substrate **290**.

[0409] In some cases, the combination of the DFE-PD **3520** and the L-BJT **804** (the device within the dashed box **3540**) may electrically behave as an HV L-BJT with the input region **2202** serving as the effective collector region of the HV L-BJT.

[0410] As discussed above, inventive aspects which enable the low voltage BiCMOS platform to be elevated to a suitably high voltage node relates to the use of a DFE-PD in series with the lower voltage devices to create high voltage DMOS and BJT devices. In the above, the high voltage potential divider region was formed in the common substrate as the BiCMOS devices. The inventors have discovered that, by forming the DFE-PD in the back-end-of-line (BEOL) above the

front-end-of-line (FEOL), further degree of freedom in monolithic integration of different devices may be achieved.

[0411] According to various aspects, an integrated circuit (IC) device comprises a metal-oxide-semiconductor (MOS) transistor and one or both of a bipolar junction transistor (e.g., an L-BJT) and a lateral double-diffused metal-oxide-semiconductor (LDMOS) transistor formed in a common silicon substrate. The IC device additionally comprises a DFE-PD or a PD region formed above a major surface of the common semiconductor substrate and integrated in a back-end-of-line (BEOL) of the IC device. In some embodiments, the high voltage potential divider region is formed of a wide bandgap semiconductor material. In some other embodiments, the high voltage potential divider region comprises a major portion comprising a lightly doped semiconductor region. In some other embodiments, in operation, the high voltage potential divider region is configured to drop a higher voltage relative to at least the MOS transistor.

[0412] According to various embodiments, the high voltage potential divider region is separated from the major surface of the common semiconductor substrate by at least one intermetal dielectric layer. Similar to the in-substrate high voltage potential divider region described above, the high voltage potential divider region formed in the BEOL also comprises a major portion comprising a lightly (N- or P-) doped semiconductor region laterally extending between heavily doped regions. One of the heavily doped regions is connected to the one or both of the BJT and the LDMOS transistor and the other one of the heavily doped regions is configured as a high voltage input configured to be biased at 5-400V. In addition, the high voltage potential divider region comprises a conductive field plate formed thereover to serve as a reduced surface field (RESURF) plate. The high voltage potential divider region is formed of a wide band gap semiconductor comprising one or more of SiC, GaN and Ga.sub.2O.sub.3.

[0413] Advantageously, by isolating silicon substrate in which low voltage devices are formed using the backend dielectric layers, the high voltage nodes are effectively separated from the low voltage substrate. The interlayer dielectric isolation can provide vertical high voltage isolation, high voltage latch-up immunity and reduction in parasitic capacitances, among other advantages.

[0414] In a similar manner as described above, various synergistic processing advantages may be realized for fabricating a metal-oxide-semiconductor (MOS) transistor and one or both of a bipolar junction transistor (BJT) and a lateral double-diffused metal-oxide-semiconductor (LDMOS) transistor formed in a common silicon substrate. The details of the synergistic processing have been described above, and the details are not repeated herein for brevity.

[0415] FIG. **36** schematically illustrates a cross-sectional view of another example high voltage device including a DFE-PD that is vertically separated and/or isolated from the substrate and is electrically connected to an L-BJT via conductive lines. An example DFE-PD **3620** is electrically connected to an LV L-BJT **804** via conductive lines and is vertically separated from the major surface (top surface) of the a substrate **290** on which the LV L-BJT **804** is fabricated. In some implementations, the DFE-PD **3620** may comprise one or more features described above with respect to the DFE-PD **3520** (FIG. **35**). The DFE-PD **3620** is fabricated above the top surface of a thick dielectric layer **3304** disposed on the top surface of the substrate **290**. In some cases, a vertical distance of a bottom surface of the DFE-PD **3620** from the top surface of a thick dielectric layer **3304** can be greater than 0.5 microns, greater than 1.0 microns, greater than 1.5 microns, greater than 2.0 microns, or be a distance in a range defined by any of these value.

[0416] In some cases, the DFE-PD **3620** may further comprise a bottom field plate **3600** disposed on the top surface of the thick dielectric layer **3304**. The bottom field plate **3600** may have a thickness (in the vertical direction), from 0.1 to 0.5 microns, or have a thickness in a range defined by any of these values.

[0417] The output region **2204** of the DFE-PD **3620** and the HD collector region of the LV L-BJT **804** can be electrically connected via a first conductive line **3000** fabricated in a metallization layer above the top surface of the substrate **290**. The field plates **2820***b*, **2820***c*, the bottom field plate

3600 and the RESURF layer **207** can be electrically connected via a second conductive line **3002** fabricated in a metallization layer above the top surface of the common substrate. In some examples, the bottom field plate **3600** may comprise a HD region serving as an ohmic contact between the field plate **3600** and the second conductive line **3002**.

[0418] The conductive lines **3002**, **3000** may be fabricated on the same or different metallization layers. The electrical connection between the bottom field plate **3600** and the field plates **2820***b*, **2820***c* results in an enhanced RESURF mechanism of the DFE-PD **3620**.

[0419] In some cases, the LV L-BJT **804** have portions formed in each of the first and a second regions **204**, **202** of the substrate **290** having opposite polarities, and extend across a boundary therebetween. In some cases, a vertical interface between the two regions of the substrate **290** may be aligned with a vertical interface between the emitter and base regions of the L-BJT **804**. The thick oxide layer **3304** may be disposed on the first region **204** of the substrate **290**. In some cases, the first and the second regions **204**, **202** can be doped wells formed in the substrate **290**, e.g., using thermal diffusion of dopants or ion implantation.

[0420] In some embodiments, the input and output regions **2202**, **2204**, the input and output drift regions **3312**, **2214**, the first substrate region **204**, the collector **207** and the emitter **206** regions of the L-BJT **803**, and the HD region **3602** of the bottom field plate **3600** can have the same polarity, which is opposite to a polarity of the second substrate region **202**, the base well, and the depletion control region **3220**.

[0421] In some cases, the combination of the DFE-PD **3620** and the L-BJT **804** (the device within the dashed box **3640**) may electrically behave as an HV L-BJT with the input region **2202** serving as the effective collector region of the HV L-BJT.

[0422] The LV L-BJT **804** in FIGS. **35** and **36** may have the same arrangement of the base well, base region, emitter region, RESURF layer, and RESURF dielectric layer, and HD collector region as the L-BJT **804** described above with respect to FIG. **8**, except for omission of the LD collector region.

[0423] Advantageously, physically separating the DFE-PD **3620** from the substrate in which the LV L-BJT **804** is fabricated provides a more reliable electrical isolation between the DFE-PD **3620** and LV the L-BJT **804** (and other low voltage devices fabricated on the substrate **290**). However, placing the bottom field plate **3600** on the thick dielectric layer **3304** can reduce the substrate area that may otherwise be available for fabricating transistors and other active devices for performing logic, switching, and analog operations. In some embodiment, moving the DFE-PD further up (e.g., increasing its vertical distance from the substrate) and separating the bottom field plate from the substrate can free up the corresponding substrate area and allow fabrication of more devices (e.g., BiCMOS devices) within a given substrate and connecting them to the DFE-PD for high voltage operation. In addition to freeing the surface area available for device fabrication, this approach can allow replacement of polysilicon with variety of wide bandgap materials (e.g., having bandgaps larger than 1.5 eV), e.g., compound semiconductors such as III-V and II-VI compound semiconductors, as the structural material of DFE-PD to improve the quality of the junctions formed between the depletion control region and the input/output drift regions. In some implementations, when a vertical distance between DFE-PD and substrate **290** is sufficiently large, the DFE-PD structure may be formed using advanced material growth and deposition techniques (e.g., for disposing large bandgap materials) that may not be used closer to eth substrate. Moreover, placing the DFE-PD at a higher level, e.g., above one or more metallization levels, facilitates enables electrical connection between a DFE-PD and multiple low voltage devices via a network of vias and lateral conductive lines.

[0424] FIG. **37** schematically illustrates a cross-sectional view of another example high voltage device including a DFE-PD **3270** that is vertically separated and/or isolated from the substrate and is electrically connected to one or more MOS transistors and BJTs. An example DFE-PD **3720** has top and bottom field plates **2820***b*, **3702**, fabricated above one or more metallization layers (e.g.,

two metallization layers) above a common substrate in which a plurality of MOS and/or bipolar devices are fabricated. By way of example, in the illustrated example, the DFE-PD **3720** is connected to an N-MOS **3702**, a PNP L-BJT **3710** and an NPN L-BJT **3708** by the bottom field plate **3702** and parallel vertical electrical connections including vias between the output region **2204** and the drain and collector regions of the N-MOS **3702**, the L-BJT **3710** and the L-BJT **3708**.
[0425] Advantageously, the conductive line that laterally extends to connect the vias to the output region **2204**, also serves as the bottom field plate **3702** of the DFE-PD **3720**.
[0426] In some implementations, a vertical distance H between the input drift region **3312** of the DFE-PD **3720** and the top surface of the substrate on which the MOS and L-BJT transistor are fabricated can be greater than 0.15, greater than 0.3, greater than 0.5, greater than 1.0, or a distance in a range defined by any of these values.
[0427] In some cases, at least a region of the DFE-PD **3720** may comprise a wide band gap material such as SiC, GaN, or Ga.sub.2O.sub.3.
[0428] In some cases, a thickness of the input region **2202**, the input drift region **3312**, and the depletion control region **3220** (of the DFE-PD **3320**, **3420**, **3520**, **3620**), along the vertical direction (along y-axis), can be substantially equal due to being formed from the same layer. In various embodiments, the thickness of the input region **2202**, the input drift region **3312**, and the depletion control region **3220**, can be from 0.15 to 0.5 microns. In some cases, the thickness of the dielectric layer **3304** (of the DFE-PD **3320**, **3420**, **3520**, **3620**), can be from be from 0.15 to 0.5 microns.
[0429] In various implementations, the input region **2202**, the input drift region **3312**, the output drift region **2204**, and the output region **2204** of the DFE-PDs **3320**, **3420** (FIG. **34**), **3520** (FIG. **35**), **3620** (FIG. **36**), and **3720** (FIG. **37**) may comprise a polysilicon layer or a wide band gap material layer disposed on a the thick dielectric layer **3304** or on portion of the dielectric cladding later **214** disposed above the thick dielectric layer **3304** or the top surface of the substrate **290**.
[0430] In various embodiments the thickness of the polysilicon layer can be from 0.1 to 0.15 microns, from 0.1 to 0.3 microns, from 0.1 to 1.0 microns, but smaller than 2.0 microns, or a thickness in a range defined by any of these values.
[0431] In some examples, the input region **2202**, the input drift region **3312**, the output drift region **224**, and the output region **2204** of the DFE-PDs **3320**, **3420**, **3520**, **3620**, and **3720** may formed in the polysilicon or wide band gap semiconductor using suitable doping techniques such as thermal diffusion, ion implantation or in-situ doping. In some examples, the thicknesses of the input region **2202**, the input drift region **3312**, the output drift region **224**, and the output region **2204** of the DFE-PDs **3320**, **3420**, **3520**, **3620**, and **3720** may vertically extend across the entire thickness of the polysilicon or wide band gap semiconductor layer. In some cases, the thermal diffusion or activation of dopants in the polysilicon layer may be achieved using a suitable technique such as rapid thermal anneal (RTA) process that does not affect the wells and doped regions already formed in the substrate **290**.
[0432] In some embodiments, the L-BJTs in any of the configurations shown in FIGS. **31**-**36**, may be replaced with a MOS transistor (e.g., MOS transistors **280** or **740** shown in FIGS. **7**B and **7**D). In the se embodiments, the output region **2204** of the corresponding DFE-PDs (e.g., DFE-PD **3206**, **3320**, **3420**, **3520**, and **3620**) can be electrically connected to the HD drain region **720** of the MOS transistor where the HD drain region **720** and the output region **2204** have the same polarities. Accordingly, the combination of a DFE-PD and the MOS transistor (the device within the dashed boxes **3240**, **3340**, **3440**, **3540**, and **3640**) may electrically behave as an HV MOS or DMOS transistor with the input region **2202** serving as an effective drain region of the DMOS.
[0433] In any one of the embodiments described above with respect to FIGS. **32-38**, thicknesses of the depletion control region **3220**, the input drift region **3312**, and the output drift region **3220** along the vertical direction can be substantially equal. In various implementations, the thickness of the depletion control region **3220**, the input drift region **3312**, or the output drift region **3220**, along the vertical direction can be from 0.1 micron to 0.2 microns, from 0.2 microns to 0.3 microns, from

0.3 microns to 0.4 microns, from 0.4 microns to 0.5 microns, or any values in a range formed by these values. In various implementations, a common thickness of the depletion control region **3220**, the input drift region **3312**, or the output drift region **3220**, along the vertical direction can be smaller than 2 micrometers.

[0434] In any one of the embodiments described above with respect to FIGS. **23-37**, a majority carrier concentration or a doping concentration in the inter-gate region **2215** and depletion control region **3220** is smaller than those of the input drift regions **2212**, **3212**, **3312**, and the output drift region **2214** (or output drift regions of potential dividers **3420**, **3520**, **3620**, **3720**, or **3820**), and/or the well **2828**, by a factor of 5, 10, 20, 30, 40, 50, 102, 103, or larger values.

[0435] In any one of the embodiments described above with respect to FIGS. **23-37**, a majority carrier concentration or a doping concentration in the inter-gate region **2215** and depletion control region **3220** is smaller than those of the input drift regions **2212**, **3212**, **3312** and the output drift region **2214** (or output drift regions of potential dividers **3420**, **3520**, **3620**, **3720**, or **3820**), and/or the well **2828**, by at least a factor of 10.

Equivalent Circuit Model

[0436] FIG. **38**A-**38**B illustrates, without being bound to any theory, an equivalent circuit to the DFE-PD described above. The secondary voltage source (V**2**, Vs) is a scaled function of the applied primary voltage (V**1**, Vp) and the primary current (I**1**) is determined by the secondary current (I**2**), where the current densities for optimum performance are inversely ratioed by the same scaling design parameters.

[0437] The represented voltage transformer is represented as a non-magnetic, no active circuitry, or a single component that scales the applied higher DC and AC voltage levels (primary, V.sub.p) to lower voltages (secondary, V.sub.s). The ratio of the two voltage nodes is a design controlled parameter that can be represented by the integer N>1.

[00001] $\frac{V_p}{V_s} = N$

[0438] The represented voltage transformer can be adjustable to target any voltage node, where the maximum planned voltage scaling transforms 0-400V into a 0-5V range. The output of the secondary terminal is directly connected to the low voltage (LV)-BiCMOS silicon substrate. The current that flows through the LV secondary side of the voltage transformer, is, is controlled by the operation of the LV circuitry. This can be translated to a current concentration according to the conduction area represented by a width, W.sub.s, and height, h:

[00002] $i_s = W_s \times h \times J_s$

[0439] No current flows through the higher voltage primary side, i.sub.p, until a current flows through the lower voltage secondary, where the ratio of the current concentration between the two sides is similarly scaled according to the design ratio, N.

[00003] $\frac{J_s}{J_p} = N$

[0440] The primary current concentration is related to the primary conduction area according to a representative width, W.sub.p, and height, h.

[00004] $i_p = W_p \times h \times J_p$

[0441] For the optimum translation of the performance achieved at the lower voltage nodes to the higher voltage nodes, the higher voltage must be capable of supporting the same current conducted by the secondary:

i.sub.p=i.sub.s

[0442] This implies the conduction width of the higher voltage node must be, N, times the width of the lower voltage secondary:

[00005] $W_p \times h \times J_p = W_s \times h \times J_s \frac{W_p}{W_s} = N$

[0443] This makes the area of the primary high voltage node, N, times larger than the lower voltage conduction area. The lower voltage area is limited by the width of the MOS channel, or the width

of the emitter terminal for the bipolar. When the voltage transformer is conducting, it can be similar to a resistive element. In the illustrated model, the combination of the LV BiCMOS components together with the vertically stacked voltage transformer are drawn as a standalone device.

[0444] Some additional nonlimiting examples of embodiments discussed above are provided below. These should not be read as limiting the breadth of the disclosure in any way.

EXAMPLE EMBODIMENTS I

[0445] 1. An integrated circuit (IC) device, comprising: [0446] a metal-oxide-semiconductor (MOS) transistor comprising a gate stack formed over a channel region thereof; and [0447] a bipolar junction transistor (BJT) comprising a layer stack formed over a collector region thereof, [0448] wherein the gate stack and the layer stack have one or more corresponding layers having a common physical dimension.

[0449] 2. An integrated circuit (IC) device, comprising: [0450] a metal-oxide-semiconductor (MOS) transistor comprising a gate stack formed over a channel region thereof; and [0451] a bipolar junction transistor (BJT) comprising a layer stack formed over a collector region thereof, [0452] wherein the gate stack and the layer stack have corresponding spacer structures formed on sidewalls thereof and having a common physical dimension.

[0453] 3. An integrated circuit (IC) device, comprising: [0454] a metal-oxide-semiconductor (MOS) transistor comprising a gate stack formed over a channel region thereof; and [0455] a bipolar junction transistor (BJT) comprising a layer stack formed over a collector region thereof, [0456] wherein the MOS transistor and the BJT have corresponding implanted diffusion regions having a common implanted dopant profile.

[0457] 4. The IC device of Embodiment 1, wherein the gate stack and the layer stack have corresponding spacer structures formed on sidewalls thereof having a common physical dimension.

[0458] 5. The IC device of Embodiment 1, wherein the MOS transistor and the BJT have corresponding implanted diffusion regions having a common implanted dopant profile.

[0459] 6. The IC device of Embodiment 2, wherein the gate stack and the layer stack have one or more corresponding layers having a common physical dimension.

[0460] 7. The IC device of Embodiment 2, wherein the MOS transistor and the BJT have corresponding implanted diffusion regions having a common implanted dopant profile.

[0461] 8. The IC device of Embodiment 3, wherein the gate stack and the layer stack have corresponding spacer structures formed on sidewalls thereof having a common physical dimension.

[0462] 9. The IC device of Embodiment 8, wherein the corresponding implanted diffusion regions include source and drain regions of the MOS transistor and one of an emitter region or a collector region of the BJT.

[0463] 10. The IC device of Embodiment 1, wherein the common physical dimension is caused by one or more of co-oxidation, co-deposition, co-etch and co-patterning of the gate stack and the layer stack.

[0464] 11. The IC device of Embodiment 2, wherein the common physical dimension is caused by one or more of co-deposition, co-etch and co-patterning of the corresponding spacer structures.

[0465] 12. The IC device of Embodiment 3, wherein the common implanted dopant profile is caused by one or more of co-implantation and co-dopant activation of the corresponding implanted diffusion regions.

[0466] 13. The IC device of any one of the above Embodiments, wherein the MOS transistor and the BJT are monolithically integrated on a common substrate.

[0467] 14. The IC device of any one of the above Embodiments, wherein the BJT is a lateral BJT having an emitter region, a base region within a base well and a collector region within a common well, wherein the emitter region, the base region, and the collector region are arranged in a lateral direction to support lateral bipolar currents, and where in the lateral direction is parallel to a main surface of a common substrate on which the BJT and MOS transistor are fabricated.

[0468] 15. The IC device of any one of the above Embodiments, wherein a base length of the BJT

is laterally extended from a first end at a vertical interface between the base region and the emitter region to a second end below an edge of the layer stack.
[0469] 16. The IC device of any one of the above Embodiments, wherein the layer stack of the BJT has a first RESURF dielectric layer that is co-deposited or co-oxidized with and has a same thickness as a first gate dielectric layer of the MOS transistor.
[0470] 17. The IC device of any one of the above Embodiments, wherein the layer stack of the BJT has a RESURF layer on the first RESURF dielectric layer that is co-deposited with and has a same thickness as a gate electrode on the first gate dielectric layer of the MOS transistor.
[0471] 18. The IC device of any one of the above Embodiments, wherein at least a portion of the RESURF layer is disposed on a second RESURF dielectric layer that is co-deposited with and has a same thickness as a gate layer on a second gate dielectric layer of the MOS transistor.
[0472] 19. The IC device of any one of the above Embodiments, wherein a thickness of the second RESURF dielectric layer and the second gate dielectric layers along a vertical direction is larger than a thickness of the first RESURF dielectric layer and the first gate dielectric layers, respectively, wherein the vertical direction is perpendicular to a main surface of a common substrate on which the BJT and MOS transistor are fabricated.
[0473] 20. The IC device of any one of the above Embodiments, wherein the second RESURF dielectric layer and the second gate dielectric layer comprise thermally grown oxide layers.
[0474] 21. The IC device of any one of the above Embodiments, wherein a lateral dimension of the layer stack in a first direction defines a drift region or a collector length of the BJT, and wherein a lateral dimension of the gate stack in a second direction defines a channel length of the MOS transistor in the first direction.
[0475] 22. The IC device of any one of the above Embodiments, wherein the first direction is parallel to the second direction.
[0476] 23. The IC device of any one of the above Embodiments, wherein a length of the layer stack in the lateral direction is substantially equal to a distance from an interface between the base region and the collector region to a vertical boundary of a lightly doped collector region.
[0477] 24. The IC device of any one of the above Embodiments, wherein the layer stack of the BJT serves as a first reduced surface field (RESURF) plate extending across a collector region of the BJT.
[0478] 25. The IC device of any one of the above Embodiments, wherein each of the layer stack of the BJT and the gate stack of the MOS transistor has formed on opposing sidewall surfaces thereof a pair of spacers that are co-deposited, co-patterned and co-etched such that each of the pair of spacers of the BJT and the pair of spacers of the MOS transistor has substantially a same lateral dimension.
[0479] 26. The IC device of any one of the above Embodiments, wherein substantially the same lateral dimension is a width at a bottom portion of the spacers.
[0480] 27. The IC device of any one of the above Embodiments, wherein the width at the bottom portion of the spacers defines a base length (LB) of the BJT and a width of a lightly-doped (LD) drain region of the MOS transistor.
[0481] 28. The IC device of any one of the above Embodiments, wherein each of the layer stack of the BJT and the gate stack of the MOS transistor has formed on opposing sidewall surfaces thereof a pair of spacers that are co-deposited, co-patterned, and etched separately such that the pair of spacers of the BJT has a first lateral dimension and the pair of spacers of the MOS transistor has a second lateral dimension.
[0482] 29. The IC device of any one of the above Embodiments, wherein the first and second lateral dimensions are first and second widths at a bottom portion of the corresponding spacers.
[0483] 30. The IC device of any one of the above Embodiments, wherein the first width defines a base length (LB) of the BJT and the second width defines a width of a lightly-doped (LD) drain region of the MOS transistor.

[0484] 31. The IC device of any one of the above Embodiments, wherein the layer stack of the BJT and the gate stack of the MOS transistor have a same lateral dimension and define one or more implanted diffusion regions for the BJT and the MOS transistor.
[0485] 32. The IC device of any one of the above Embodiments, wherein at least one implanted diffusion region of the BJT is co-implanted with an implanted diffusion region of MOS transistor with the same implanted dopant profile.
[0486] 33. The IC device of any one of the above Embodiments, wherein the least one implanted diffusion region of the BJT comprises an LD or HD collector region of the BJT.
[0487] 34. The IC device of any one of the above Embodiments, wherein the layer stack and the gate stack respectively define a first end of a base region of the BJT and a first end of a lightly-doped (LD) drain region of the MOS transistor that are co-implanted.
[0488] 35. The IC device of any one of the above Embodiments, wherein a second end of a base region of the BJT and a second end of the lightly-doped (LD) drain region of the MOS transistor are defined by a spacer structure formed on respective sidewalls of the layer stack and the gate stack.
[0489] 36. The IC device of any one of the above Embodiments, wherein a first end of the base region of the BJT is defined by a spacer structure formed on a sidewall of the layer stack and the second end of the base region of the BJT is defined by a diffusion length of dopants diffused from an initial base well from which the base well is formed.
[0490] 37. The IC device of any one of the above Embodiments, wherein a doping profile of the base region comprises a gradient of the doping concentration in the lateral direction.
[0491] 38. The IC device of any one of the above Embodiments, wherein the LD drain region is an n-doped LD (NLD) region of an n-channel MOS transistor (NMOS) that is co-implanted with an n-type base region of a PNP BJT.
[0492] 39. The IC device of any one of the above Embodiments, wherein the LD drain region is a p-doped LD (PLD) region of a p-channel MOS transistor (PMOS) that is co-implanted with a p-type base region of an NPN BJT.
[0493] 40. The IC device of any one of the above Embodiments, wherein a spacer of the BJT and a spacer of the MOS transistor have a same lateral dimension and define one or more implanted diffusion regions for the BJT and the MOS transistor.
[0494] 41. The IC device of any one of the above Embodiments, wherein at least one implanted diffusion region of the BJT is co-implanted with an implanted diffusion region of the MOS transistor with the same implanted dopant profile.
[0495] 42. The IC device of any one of the above Embodiments, wherein the spacer of the BJT and the spacer of the MOS transistor respectively define one end of an emitter region of the BJT and one end of a source/drain (S/D) region of the MOS transistor that are co-implanted.
[0496] 43. The IC device of any one of the above Embodiments, wherein at least one implanted diffusion region of the BJT has a different implanted dopant profile compared to the corresponding implanted diffusion region of the MOS transistor.
[0497] 45. The IC device of any one of the above Embodiments wherein the S/D region is an n-doped S/D region of an n-channel MOS transistor (NMOS) that is co-implanted with an n-type emitter region of an NPN BJT.
[0498] 46. The IC device of any one of the above Embodiments, wherein the S/D region is a p-doped S/D region of a p-channel MOS transistor (PMOS) that is co-implanted with a p-type emitter region of PNP BJT.
[0499] 47. The IC device of any one of the above Embodiments, wherein a collector region of the BJT and channel region of the MOS transistor are co-implanted.
[0500] 48. The IC device of any one of the above Embodiments, wherein the channel region is an n-doped well region of a p-channel MOS transistor (PMOS) that is co-implanted with an n-type collector region of an NPN BJT.

[0501] 49. The IC device of any one of the above Embodiments, wherein the n-type collector region comprises a lightly doped region that is co-implanted with an n-doped LD (NLD) region of an n-channel MOS transistor (NMOS) and an n-type base region of a PNP BJT.
[0502] 50. The IC device of any one of the above Embodiments, wherein the n-type collector region comprises a heavily doped region that is co-implanted with an n-doped S/D region of an n-channel MOS transistor (NMOS) and an n-type emitter region of an NPN BJT.
[0503] 51. The IC device of any one of the above Embodiments, wherein the channel region is a p-doped well region of an n-channel MOS transistor (NMOS) that is co-implanted with a p-type collector region of PNP BJT.
[0504] 52. The IC device of any one of the above Embodiments, wherein the p-type collector region comprises a lightly doped region that is co-implanted with a p-doped LD (PLD) region of a p-channel MOS transistor (PMOS) and a p-type base region of an NPN BJT.
[0505] 53. The IC device of any one of the above Embodiments, wherein the p-type collector region comprises a heavily doped region that is co-implanted with a p-doped S/D region of a p-channel MOS transistor (PMOS) and a p-type emitter region of a PNP BJT.
[0506] 54. The IC device of any one of the above Embodiments, wherein the base well is formed in the common well.
[0507] 55. The IC device of any one of Embodiments above the above, wherein the base well comprises a lightly doped (LD) region and at least one highly doped (HD) region.
[0508] 56. The IC device of any one of the above Embodiments, wherein the at least one HD region is adjacent to the layer stack and the emitter region.
[0509] 57. The IC device of any one of the above Embodiments, wherein the base well is partially formed in the common well and a second region having an opposite polarity compared to that of the common well, the second region having an interface with the common well, the interface being perpendicular to a main surface of a substrate on which the BJT and MOS transistor are fabricated.
[0510] 58. The IC device of any one of the above Embodiments, wherein the emitter region is disposed between the HD region of the base well and the layer stack.
[0511] 59. The IC device of any one of the above Embodiments, wherein a length of the base well along a lateral direction parallel to a substrate and extended from an edge of the layer stack to an isolating dielectric structure, is larger than a length of an LD collector region along the same lateral direction and extended from the opposing edge of the layer stack to another isolating dielectric structure, by at least 1 micrometer.
[0512] 60. The IC device of any one of the above Embodiments, wherein a length of the base well along a lateral direction parallel to a substrate and extended from an edge of the layer stack to an isolating dielectric structure, is substantially equal to a length of an LD collector region along the same lateral direction and extended from the opposing edge of the layer stack to another isolating dielectric structure.
[0513] 61. The IC device of any one of the above Embodiments, further comprising an interfacial dielectric layer on the emitter region and a vertical emitter region disposed on the interfacial dielectric layer, the vertical emitter extended in a vertical direction to a major surface of a substrate on which the BJT and the MOS transistor are formed.
[0514] 62. The IC device of any one of the above Embodiments, wherein the vertical emitter region disposed on the emitter region comprises polysilicon.
[0515] 63. The IC device of any one of the above Embodiments, wherein a thickness of the interfacial dielectric layer is less than 0.3 nm.
[0516] 64. The IC device of any of the above Embodiments, wherein the BJT is electrically isolated in a vertical direction by a buried dielectric layer, and at least one lateral direction by isolating dielectric structures, wherein the vertical direction is perpendicular to a main surface of a substrate on which the BJT and the MOS transistor are fabricated.
[0517] 65. The IC device of any one of the above Embodiments, wherein a base well and an LD

collector region of the BJT are extended in the vertical direction to a top surface of the buried dielectric layer, wherein a vertical distance between the top surface of the buried dielectric layer and base well or the LD collector region is less than 10 nm.

[0518] 66. The IC device of any one of the above Embodiments, wherein the isolating dielectric structures that laterally bound the base well and the LD collector region are in contact with the buried dielectric layer.

[0519] 67. The IC device of any one of the above Embodiments, wherein a distance between a lower boundary of the dielectric structures that laterally bound the base well and the LD collector region and a top boundary of the buried dielectric layer is less than 10 nm.

[0520] 68. The IC device of any one of the above Embodiments, wherein the buried dielectric layer comprises a buried oxide layer.

[0521] 69. The IC device of any one of the above Embodiments, wherein the isolating dielectric structures comprise trench oxide.

[0522] 70. The IC device of any one of the above Embodiments, wherein the isolating dielectric structures comprise thermally grown oxide (TGO).

[0523] 71. The IC device of any one of the above Embodiments, wherein the base length is less than 500 nm.

[0524] 72. The IC device of any one of the above Embodiments, wherein the metal-oxide-semiconductor (MOS) transistor further a comprises a first field plate extended in the lateral direction over a portion of the second gate dielectric layer, and the BJT comprises a second field plate extended in the lateral direction over a portion of the second RESURF dielectric layer, wherein the first field plate and the second field plate are fabricated in a first common metallization layer above the gate stack and the layer stack respectively.

[0525] 73. The IC device of any one of the above Embodiments, wherein the first field plate and the second field plate are co-fabricated and have the same thickness along a vertical direction perpendicular to the lateral direction.

[0526] 74. The IC device of any one of the above Embodiments, wherein the first field plate is electrically connected to the gate layer and the second filed plate is connected to RESURF layer.

[0527] 75. The IC device of any one of the above Embodiments, wherein the metal-oxide-semiconductor (MOS) transistor further a comprises a third field plate extended in the lateral direction over a portion of the second gate dielectric layer, and the BJT comprises a fourth field plate extended in the lateral direction over a portion of the second RESURF dielectric layer, wherein the third field plate and the fourth field plate are fabricated in a second common metallization layer above the first common metallization layer.

[0528] 76. The IC device of any one of the above Embodiments, wherein the third field plate and the fourth field plate co-fabricated and have the same thickness along a vertical direction perpendicular to the lateral direction.

[0529] 78. The IC device of any one of the above Embodiments, wherein a base length of the BJT extends in a lateral direction along a major surface of the common substrate from a first end at a vertical interface between a base well and an emitter region formed in the base well, to a second end below an edge of the layer stack.

[0530] 79. The IC device of any one of the above Embodiments, wherein the spacer structure of the BJT and the spacer structure of the MOS transistor have a same lateral dimension and partly define one or more implanted diffusion regions for the BJT and the MOS transistor.

[0531] 80. The IC device of any one of the above Embodiments, wherein a width of a bottom portion of the spacer structure of the BJT defines a base length of the BJT and a width of the spacer structure of the MOS transistor defines on end of a lightly-doped drain region of the MOS transistor.

[0532] 81. The IC device of any one of the above Embodiments, wherein the base length of the BJT and the width of the lightly-doped drain region of the MOS transistor are substantially equal.

[0533] 84. The IC device of any one of the above Embodiments, wherein the common implanted dopant profile is caused by co-implantation that is self-aligned by the gate stack and the layer stack after forming the spacer structures.
[0534] 85. The IC device of any one of the above Embodiments, wherein the corresponding implanted diffusion regions include lightly doped regions surrounding source and drain regions of the MOS transistor and one of an emitter region or a collector region of the BJT.
[0535] 86. The IC device of Embodiment 19, wherein the common implanted dopant profile is caused by co-implantation that is self-aligned by the gate stack and the layer stack, prior to forming spacer structures on sidewalls of the gate stack and the layer stack.

EXAMPLE EMBODIMENTS II

[0536] 1. A lateral bipolar junction transistor (BJT), comprising: [0537] an emitter region formed in a base well; [0538] a lightly doped collector region separated in a lateral direction from the base well by a drift region doped with a dopant of a same type at a lower dopant concentration relative to the lightly doped collector region; and [0539] a layer stack formed on the drift region; [0540] wherein a boundary of the base well or the emitter region is aligned, in a vertical direction crossing the lateral direction, with an edge of the layer stack.
[0541] 2. A lateral bipolar junction transistor (BJT), comprising: [0542] an emitter region formed in a base well; [0543] a lightly doped collector region separated in a lateral direction from the base well by a drift region doped with a dopant of a same type at a lower dopant concentration relative to the lightly doped collector region; and [0544] a layer stack formed on the drift region having a spacer formed on a sidewall thereof; [0545] wherein a base length of the lateral BJT, extending in the lateral direction between the emitter region and the drift region, is defined by a lateral width of a bottom portion of the spacer formed on a sidewall of the layer stack.
[0546] 3. A lateral bipolar junction transistor (BJT), comprising: [0547] an emitter region formed in a base well; [0548] a heavily doped collector region separated in a lateral direction from the base well by a drift region doped with a dopant of a same type at a lower dopant concentration relative to the heavily doped collector region; [0549] a layer stack formed at least on a first lateral section of the drift region, the layer stack including a conductive reduced surface field (RESURF) layer.
[0550] 4. The lateral BJT of Embodiment 1, wherein a base length of the lateral BJT, extending between the emitter region and drift region, is defined by a lateral width of a bottom portion of a spacer formed on a sidewall of the layer stack.
[0551] 5. The lateral BJT of Embodiment 1, wherein the layer stack comprises: [0552] a dielectric layer formed on the drift region, and [0553] a conductive reduced surface field (RESURF) layer formed on the dielectric layer.
[0554] 6. The lateral BJT of Embodiment 2, wherein a vertical boundary between the base well and the emitter region is aligned, in a vertical direction crossing the lateral direction, with an edge of the layer stack.
[0555] 7. The lateral BJT of Embodiment 2, wherein the layer stack of the lateral BJT comprises a dielectric layer vertically interposed between the drift region and a conductive reduced surface field (RESURF) layer.
[0556] 8. The lateral BJT of Embodiment 3, wherein the layer stack further comprises a thin dielectric layer vertically interposed between the RESURF layer and the drift region.
[0557] 9. The lateral BJT of Embodiment 8, further comprising a thick dielectric layer formed on a second lateral section of the drift region extending from the layer stack to the heavily doped collector region.
[0558] 10. The lateral BJT of any one of the above Embodiments, wherein a vertical boundary of the base well or the emitter region is aligned with an edge of the layer stack
[0559] 11. The lateral BJT of any one of the above Embodiments, wherein the base well comprises a base region extended in the lateral direction from a first end to a second end, wherein one of the first and second ends is aligned with an edge of the layer stack.

[0560] 13. The lateral BJT of any one of the above Embodiments, wherein a length of the layer stack in the lateral direction is substantially equal to a length of the drift region in the lateral direction.
[0561] 14. The lateral BJT of any one of the above Embodiments, wherein a base length (LB) of the L-BJT is a lateral distance from the first end aligned with an edge of the layer stack to the second end, and the base length is defined by a thermal diffusion length.
[0562] 15. The lateral BJT of any one of the above Embodiments, wherein the base length (LB) is less than 500 nm.
[0563] 16. The lateral BJT of any one of the above Embodiments, wherein the emitter region, the base region, and the collector region are arranged in the lateral direction to support bipolar current in the lateral direction.
[0564] 17. The lateral BJT of any one of the above Embodiments, wherein the layer stack of the BJT comprises a RESURF dielectric layer, and a conductive RESURF layer disposed on the RESURF dielectric layer.
[0565] 18. The lateral BJT of any one of the above Embodiments, wherein the second RESURF dielectric layer comprises a thermally grown oxide layer.
[0566] 19. The lateral BJT of any one of the above Embodiments, wherein the second RESURF layer is configured to reduce a lateral component of an electric field in the drift region.
[0567] 20. The lateral BJT of any one of the above Embodiments, wherein a vertical boundary of the HD collector region is aligned with a spacer formed on a sidewall of the layer stack.
[0568] 21. The lateral BJT of any one of the above Embodiments, wherein a vertical boundary of the HD collector region is aligned another edge of the layer stack.
[0569] 22. The lateral BJT of any one of the above Embodiments, further comprising a lightly doped (LD) collector region in which the HD collector region is formed on a second sidewall of the layer stack opposite to the first sidewall.
[0570] 23. The lateral BJT of any one of the above Embodiments, wherein a peak of an implanted dopant profile of the base well of the BJT in the vertical direction is substantially positioned at a lateral interface between the base well and the emitter region.
[0571] 24. The lateral BJT of any one of the above Embodiments, wherein the base well is partially formed in the common well and a second region having an opposite polarity compared to that of the common well, the second region having a vertical interface with the common well.
[0572] 25. The lateral BJT of any one of the above Embodiments, wherein a length of the emitter region in the lateral direction, is larger than a length of the LD collector region along the same lateral direction by at least 0.3 micrometer.
[0573] 29. The lateral BJT of any one of the above Embodiments, wherein a thickness of the interfacial dielectric layer is less than 0.3 nm.
[0574] 30. The lateral BJT of any one of the above Embodiments, wherein interfacial dielectric layer comprises an oxide layer.
[0575] 31. The lateral BJT of any one of the above Embodiments, wherein the BJT is electrically isolated in a vertical direction by a buried dielectric layer, and at least in one lateral direction by isolating dielectric structures.
[0576] 32. The lateral BJT of any one of the above Embodiments, wherein the base well and the LD collector region are extended in the vertical direction to a top surface of the buried dielectric layer, wherein a vertical distance between the top surface of the buried dielectric layer and base well or the LD collector region is less than 500 nm.
[0577] 33. The lateral BJT of any one of the above Embodiments, wherein the isolating dielectric structures that laterally bound the base well and the LD collector region are in contact with the buried dielectric layer.
[0578] 34. The lateral BJT of any one of the above Embodiments, wherein a distance between a lower boundary of the dielectric structures that laterally bound the base well and the LD collector

region and a top boundary of the buried dielectric layer is less than 10 nm.
[0579] 35. The lateral BJT of any one of the above Embodiments, wherein the buried dielectric layer comprises a buried oxide layer.
[0580] 36. The lateral BJT of any one of the above Embodiments, wherein the isolating dielectric structures comprise trench oxide.
[0581] 37. The lateral BJT of any one of the above Embodiments, wherein the isolating dielectric structures comprise thermally grown oxide (TGO).
[0582] 38. The lateral BJT of any one of the above Embodiments, wherein the RESURF layer is configured to provide a substantially constant lateral electric field component along the drift region.
[0583] 40. The lateral BJT of any one of the above Embodiments, wherein the emitter region comprises a vertical emitter portion extending in the vertical direction above a surface of a substrate having the base well formed therein.
[0584] 41. The lateral BJT of any one of the above Embodiments, wherein the vertical emitter portion comprises polysilicon.
[0585] 42. The lateral BJT of any one of the above Embodiments, further comprising an interfacial dielectric layer formed between the vertical emitter portion and the top surface of the substrate.
[0586] 45. The lateral BJT of any one of the above Embodiments, wherein the emitter region, a base region, and the collector region of the lateral BJT are arranged in the lateral direction, and wherein the base region comprises a region of the of the base well extending in the lateral direction between the emitter region and the drift region.
[0587] 46. The lateral BJT of any one of the above Embodiments, wherein the RESURF layer laterally extends from a vertical interface between the base well and the drift region towards the heavily doped collector region to cover a portion of the thick dielectric layer.
EXAMPLE EMBODIMENTS III
[0588] 1. An integrated circuit (IC) device, comprising: [0589] a metal-oxide-semiconductor (MOS) transistor comprising a heavily doped (HD) drain region, a gate stack, a drain region extension extending in a lateral direction from the HD drain region to an edge of the gate stack, and at least one drain field plate extending over at least 20% of a length of the drain region extension; and [0590] a bipolar junction transistor (BJT) comprising a heavily doped (HD) collector region, a layer stack, a drift region extension extending in the lateral direction from the HD collector region to an edge of the layer stack, and at least one field plate extending over at least 20% of the drift region extension; [0591] wherein at least one drain field plate and at least one field plate have at least one common physical dimension.
[0592] 2. An integrated circuit (IC) device, comprising: [0593] a metal-oxide-semiconductor (MOS) transistor comprising a heavily doped (HD) drain region, a gate stack, a drain region extension extending in a lateral direction from the HD drain region to an edge of the gate stack, and a thick dielectric layer extending over the drain region extension; and [0594] a bipolar junction transistor (BJT) comprising a heavily doped (HD) collector region, a layer stack, a drift region extension extending in the lateral direction from the HD collector region to an edge of the layer stack, and a thick isolating dielectric layer extending over the drift region extension, [0595] wherein the thick dielectric layer and the thick isolating dielectric layer have at least one common physical dimension.
[0596] 3. An integrated circuit (IC) device, comprising: [0597] a metal-oxide-semiconductor (MOS) transistor comprising a heavily doped (HD) drain region, a gate stack and a drain region extension extending in a lateral direction from the HD drain region to an edge of the gate stack, the gate stack comprising a gate layer extending over a gate dielectric layer and a portion of the drain region extension; and [0598] a bipolar junction transistor (BJT) comprising a heavily doped (HD) collector region, a layer stack and a drift region extension extending in the lateral direction from the HD collector region to an edge of the layer stack, and a reduced surface field (RESURF) layer extending over a RESURF dielectric layer and a portion of the drift region extension, [0599]

wherein the gate layer and the RESURF layer have least one common physical dimension.
[0600] 4. The IC device of Embodiment 1, wherein the at least one common physical dimension is caused by one or more of co-deposition, co-etch, and co-patterning of the drain field plate and the field plate.
[0601] 5. The IC device of Embodiment 1, wherein the MOS transistor further comprises a gate layer extending over a gate dielectric layer and further over a portion of the drain region extension, and the BJT further comprises a reduced surface field (RESURF) layer extending over a RESURF dielectric layer and further over a portion of the drift region extension, and wherein the gate layer and the RESURF layer, have least one common physical dimension.
[0602] 6. The IC device of Embodiment 1, wherein the MOS transistor further comprises a thick dielectric layer extending over the drain region extension, and wherein the BJT further comprises a thick isolating dielectric layer extending over the drift region extension, and wherein the thick dielectric layer and thick isolating dielectric layer have at least one common physical dimension.
[0603] 7. The IC device of Embodiment 2, wherein the at least one common physical dimension is caused by one or more of co-oxidation, co-deposition, co-etch, and co-patterning of the thick dielectric layer and thick isolating dielectric layer.
[0604] 8 The IC device of Embodiment 2, wherein the MOS transistor further comprises a gate layer extending over a gate dielectric layer and further over a portion of the drain region extension, and the BJT further comprises a reduced surface field (RESURF) layer extending over a RESURF dielectric layer and further over a portion of the drift region extension, and wherein the gate layer and the RESURF layer, have least one common physical dimension.
[0605] 9. The IC device of Embodiment 2, wherein the MOS transistor further comprises at least one drain field plate extending over at least 20% of the drain region extension, wherein the BJT further comprises at least one field plate extending over at least 20% of the drift region extension, and wherein the at least drain field plate and the at least one field plate have at least one common physical dimension.
[0606] 10. The IC device of Embodiment 3, wherein the common physical dimension is caused by one or more of co-deposition, co-etch, and co-patterning of the gate layer and the RESURF layer.
[0607] 11. The IC device of Embodiment 3, wherein the MOS transistor further comprises at least one drain field plate extending over at least 20% of the drain region extension, wherein the BJT further comprises at least one field plate extending over at least 20% of the drift region extension, and wherein the at least one drain field plate and the at least one field plate have at least one common physical dimension.
[0608] 12. The IC device of Embodiment 3, wherein the MOS transistor further comprises a thick dielectric layer extending over the drain region extension, wherein the BJT further comprises a thick isolating dielectric layer of the drift region extension, and wherein the thick dielectric layer and thick isolating dielectric layer, have at least one common physical dimension.
[0609] 13. An integrated circuit (IC) device of any one of the above Embodiments, wherein: [0610] the gate stack is formed over a channel region; and [0611] the layer stack is formed over a first section of the drift region, [0612] wherein the gate stack and the layer stack have corresponding spacer structures formed on sidewalls thereof having a common physical dimension.
[0613] 14. The IC device of any one of the above Embodiments, wherein the MOS transistor and the BJT have at least one corresponding implanted diffusion region having a common implanted dopant profile.
[0614] 15. The IC device of any one of the above Embodiments, wherein the common physical dimension is caused by one or more of co-oxidation, co-deposition, co-etch and co-patterning of the gate stack and the layer stack.
[0615] 16. The IC device of Embodiment 2, wherein the common physical dimension is caused by one or more of co-deposition, co-etch and co-patterning of the corresponding spacer structures.
[0616] 17. The IC device of Embodiment 3, wherein the common implanted dopant profile is

caused by one or more of co-implantation and co-dopant activation of the corresponding implanted diffusion regions.
[0617] 18. The IC device of any one of the above Embodiments, wherein the MOS transistor and the BJT are monolithically integrated on a common substrate.
[0618] 19. The IC device of any one of the above Embodiments, wherein the BJT is a lateral BJT having an emitter region formed in the base well, and a base region within a base well, wherein the emitter region, the base region, and the HD collector region are arranged in a lateral direction to support lateral bipolar currents.
[0619] 20. The IC device of any one of the above Embodiments, wherein at least one of the drain plates and at least one of the field plates comprise a metal.
[0620] 21. The IC device of the Embodiment 9, wherein at least two drain plates are separated in the vertical direction by at least 0.5 micrometers and at least two field plates are separated in the vertical direction by at least 0.5 micrometers.
[0621] 22. The IC device of any one of the above Embodiments, wherein the drain plate and at least one of the field plates comprise polysilicon.
[0622] 23. The IC device of any one of the above Embodiments, wherein a base length of the BJT is laterally extended from a first end at a vertical interface between the base region and the emitter region to a second end below an edge of the layer stack.
[0623] 24. The IC device of any one of the above Embodiments, wherein the layer stack of the BJT comprises a first field plate on a RESURF dielectric layer and the MOS transistor comprises a gate layer on a gate dielectric layer, wherein the first field plate and the RESURF dielectric layer, are co-deposited with and have same thickness as the gate layer and the gate dielectric layer, respectively.
[0624] 25. The IC device of any one of the above Embodiments, wherein the BJT comprises a thick isolating dielectric layer that is co-deposited with and has a same thickness as a thick drain dielectric layer of the MOS transistor.
[0625] 26. The IC device of any one of the above Embodiments, wherein a thickness of the thick isolating dielectric layer and the thick channel dielectric layers along the vertical direction are larger than a thickness of the RESURF dielectric layer and the gate dielectric layer, respectively.
[0626] 27. The IC device of any one of the above Embodiments, wherein the second RESURF dielectric layer and the second gate dielectric layer comprise thermally grown oxide layers.
[0627] 28. The IC device of any one of the above Embodiments, wherein a lateral dimension of the RESURF dielectric layer and the thick isolating dielectric layer define a length of the drift region on the BJT.
[0628] 29. The IC device of any one of the above Embodiments, wherein a second field plate of the BJT and the drain plate of the MOS transistor are disposed on the thick isolating dielectric layer and the thick drain dielectric layer respectively.
[0629] 30. The IC device of any one of the above Embodiments, wherein a base length (LB) of the BJT and a width of a lightly-doped (L.sub.D) drain region of the MOS transistor, are defined by the corresponding spacer structures having a common physical dimension.
[0630] 31. The IC device of any one of the above Embodiments, wherein the layer stack of the BJT and the gate stack of the MOS transistor have a same lateral dimension and define boundaries of the base well of the BJT and the LD source region of the MOS transistor, respectively.
[0631] 32. The IC device of any of the Embodiments above, wherein lengths of the extended drift region and the drift region extension in the lateral direction are larger than 0.5 micrometers.
[0632] 33. The IC device of any one of the above Embodiments, wherein a length of the base region in the lateral direction is defined by thermal diffusion of dopants.
[0633] 34. The IC device of any one of the above Embodiments, wherein a peak of doping profile of the base well along the vertical direction is at or near a lateral boundary of emitter region therein.

[0634] 35. The IC device of any one of the above Embodiments, wherein the base well is an n-doped LD region of an PNP BJT that is co-implanted with an LD source region of an n-channel DMOS transistor (NDMOS).
[0635] 36. The IC device of any one of the above Embodiments, wherein the base well is an p-doped LD region of an NPN BJT that is co-implanted with an LD source region of a p-channel DMOS transistor (NDMOS).
[0636] 37. The IC device of any one of the above Embodiments, wherein the HD collector region is an n-doped LD region of an NPN BJT that is co-implanted with an HD drain region of an n-channel DMOS transistor (NDMOS).
[0637] 38. The IC device of any one of the above Embodiments, wherein the HD collector region is an p-doped LD region of an PNP BJT that is co-implanted with an HD drain region of a p-channel DMOS transistor (NDMOS).
[0638] 39. The IC device of any one of the above Embodiments, wherein at least one implanted region of the BJT has a different implanted dopant profile compared to the corresponding implanted diffusion region of the MOS transistor.
[0639] 40. The IC device of any one of the above Embodiments, wherein at least a portion of the base well and the HD drain region are formed in a common well in the common substrate.
[0640] 41. The IC device of any one of the above Embodiments, wherein the base well is partially formed in the common well and a second region having an opposite polarity compared to that of the common well, the second region having an interface with the common well, the interface being perpendicular to the lateral direction.
[0641] 42. The IC device of any one of the above Embodiments, a length of the emitter region along the lateral direction, is larger than a length of an LD collector region along the lateral direction by at least 0.3 micrometer.
[0642] 43. The IC device of any one of the above Embodiments, further comprising an interfacial dielectric layer on the emitter region and a vertical emitter region disposed on the interfacial dielectric layer, the vertical emitter extended in a vertical direction perpendicular to the lateral direction.
[0643] 44. The IC device of any one of the above Embodiments, wherein the vertical emitter region disposed on the emitter region comprises polysilicon.
[0644] 45. The IC device of any one of the above Embodiments, wherein a thickness of the interfacial dielectric layer is less than 0.3 nm.
[0645] 46. The IC device of any one of the above Embodiments, wherein the BJT is electrically isolated in a vertical direction by a buried dielectric layer, and at least one lateral direction by isolating dielectric structures, wherein the vertical direction is perpendicular to eth lateral direction.
[0646] 47. The IC device of any one of the above Embodiments, wherein the base well and the HD collector region of the BJT are extended in the vertical direction to a top surface of the buried dielectric layer, wherein a vertical distance between the top surface of the buried dielectric layer and base well or the HD collector region is less than 10 nm.
[0647] 48. The IC device of any one of the above Embodiments, wherein the isolating dielectric structures that laterally bound the base well and the HD collector region are in contact with the buried dielectric layer.
[0648] 49. The IC device of any one of the above Embodiments, wherein a distance between a lower boundary of the dielectric structures that laterally bound the base well and the HD collector region and a top boundary of the buried dielectric layer is less than 5 nm.
[0649] 50. The IC device of any one of the above Embodiments, wherein the buried dielectric layer comprises a buried oxide layer.
[0650] 51. The IC device of any one of the above Embodiments, wherein the isolating dielectric structures comprise trench oxide.
[0651] 52. The IC device of any one of the above Embodiments, wherein the isolating dielectric

structures comprise thermally grown oxide (TGO).
[0652] 53. The IC device of any one of the above Embodiments, wherein the base length is less than 500 nm.
[0653] 54. The IC device of any one of the above Embodiments, wherein thicknesses of the isolating dielectric layer and the thick isolating dielectric layer are greater than the thicknesses of the RESURF dielectric layer and the gate dielectric layer.
[0654] 55. The IC device of any one of the above Embodiments, wherein the layer stack of the BJT and the gate stack of the MOS transistor have a same lateral dimension and respectively define boundaries of a base well of the BJT and a low doped source or drain region of the MOS transistor.
[0655] 56. The IC device of any one of the above Embodiments, wherein the RESURF layer and the gate layer comprise polysilicon.
[0656] 58. The IC device of any one of the above Embodiments, wherein the gate stack and the layer stack have corresponding spacer structures formed on sidewalls thereof and having a common physical dimension, and wherein a boundary of a heavily-doped source region of the MOS transistor and a boundary of an emitter region of the BJT are defined by the corresponding spacer structures.
[0657] 61. The IC device of any one of the above Embodiments, wherein at least one drain field plate and at least one field plate comprise metal.
EXAMPLE EMBODIMENTS IV
[0658] 1. A bipolar junction transistor (BJT) formed in a substrate, the BJT comprising: [0659] a base well; [0660] an emitter region formed in the base well; [0661] a heavily doped (HD) collector region separated in a lateral direction from the base well by a drift region, [0662] a first conductive field plate disposed over a first lateral section of the drift region spanning greater than 20% of a length of the drift region in the lateral direction, [0663] wherein the emitter region, the drift region, and the HD collector region have a same polarity that is opposite to a polarity of the base well.
[0664] 2. A bipolar junction transistor (BJT) formed in a substrate, the BJT comprising: [0665] a base well; [0666] an emitter region formed in the base well; and [0667] a heavily doped (HD) collector region separated in a lateral direction from the base well by a drift region having the HD collector region formed therein; [0668] wherein the drift region has a lower dopant concentration relative to that of the HD collector region and of the base well; and [0669] wherein the emitter region, the drift region, and the HD collector region have a same polarity that is opposite to a polarity of the base well.
[0670] 3. A bipolar junction transistor (BJT) formed in a substrate, the BJT comprising: [0671] a base well; [0672] an emitter formed in the base well; [0673] a heavily doped (HD) collector region separated in a lateral direction from the base well by a drift region; and [0674] a thick dielectric layer disposed on a first lateral section of the drift region, [0675] wherein the first lateral section is longer than 20% of a length of the drift region in the lateral direction, and [0676] wherein the emitter region, drift region, and the HD collector region have a same polarity opposite to a polarity of the base well.
[0677] 4. The BJT of Embodiment 1, wherein a dopant concentration in the drift region is less than dopant concentrations in the HD collector region and the base well.
[0678] 5. The BJT of Embodiment 1, further comprising a thick dielectric layer disposed on the first lateral section of the drift region.
[0679] 6. The BJT of Embodiment 5, further comprising a second conductive field plate disposed over a second lateral section of the drift region extending from the base well to the first lateral section of the drift region.
[0680] 7. The BJT of Embodiment 2, further comprising a thick dielectric layer disposed on a first lateral section of the drift region, wherein the first lateral section is longer than 20% of a length of the drift region in the lateral direction.
[0681] 8. The BJT of Embodiment 7, further comprising a thin dielectric layer laterally extending

from an edge of the thick dielectric region to the base well, the thin dielectric layer having a thickness less than a thickness of the thick dielectric layer.

[0682] 9. The BJT of Embodiment 7, further comprising first conductive field plate disposed above a first lateral section of the drift region, wherein the first lateral section is longer than 20% of a length of the drift region in the lateral direction.

[0683] 10. The BJT of claim **2**, wherein a base region of the base well, the emitter region, the drift region, and the HD collector region are arranged in the lateral direction, the base region having a base length defined by a spacer structure formed above the substrate.

[0684] 11. The BJT of Embodiment 3, wherein a dopant concentration in the drift region is less than dopant concentrations in the HD collector region and the base well,

[0685] 12. The BJT of Embodiment 3, further comprising a first conductive field plate disposed above the thick dielectric layer.

[0686] 13. The BJT of the any one of the above Embodiments, wherein the second conductive field plate is disposed on a RESURF dielectric layer, the RESURF dielectric layer being above the second lateral section of the drift region.

[0687] 14. The BJT of the any one of the above Embodiments, wherein a thickness of the thick isolating dielectric layer along the vertical direction is at least 0.1 nanometer thicker than that of the RESURF dielectric layer.

[0688] 15. The BJT of the any one of the above Embodiments, wherein the first, second, and the third conductive field plates are electrically connected to each other.

[0689] 16. The BJT of the any one of the above Embodiments, wherein the third conductive field plate is electrically connected to the conductive first field plate via a vertical conductive line.

[0690] 17. The BJT of the any one of the above Embodiments, wherein a vertical distance between the third conductive field plate and the first conductive field plate is least 0.5 micrometer.

[0691] 18. The BJT of the any one of the above Embodiments, wherein the thick isolating dielectric layer is laterally extended from an edge of the RESURF dielectric layer to the HD collector region.

[0692] 19. The BJT of the any one of the above Embodiments, wherein the second conductive field plate is electrically connected to the first conductive field plate via at least one vertical conductive line.

[0693] 20. The BJT of the any one of the above Embodiments, wherein the vertical boundary of the base well is aligned with the edge of the second conductive field plate.

[0694] 21. The BJT of the any one of the above Embodiments, further comprising a spacer formed on a sidewall of the second conductive field plate, wherein a vertical boundary of the emitter region is aligned with an edge of the spacer, and a length of a base region (L.sub.B) of the BJT in the lateral direction is defined by a length of a bottom portion of the space in the lateral direction.

[0695] 28. The BJT of the any one of the above Embodiments, wherein when the BJT is biased a lateral component of a lateral electric field in the drift region is substantially constant along the drift region.

[0696] 22. The BJT of the any one of the above Embodiments, wherein when the BJT is biased, a voltage drop along the drift region is larger than 80 Volts.

[0697] 23. The BJT of the any one of the above Embodiments, wherein when the BJT is biased, a voltage drop along the drift region is larger than 100 Volts.

[0698] 24. The BJT of the any one of the above Embodiments, wherein when the BJT is biased, a voltage drop along the drift region is larger than 150 Volts.

[0699] 25. The BJT of the any one of the above Embodiments, wherein when the BJT is biased, a voltage drop along the second lateral section of the drift region is larger than a voltage drop along the first section of the drift region.

[0700] 26. The IC device of the any one of the above Embodiments, wherein (LB) is less than 500 nm.

[0701] 27. The BJT of the any one of the above Embodiments, further comprising a third

conductive field plate disposed over a third lateral section of the drift region that is non-overlapping with the first and the second lateral sections of the drift region.
[0702] 28. The BJT of the any one of the above Embodiments, wherein the first conductive field plate comprises metal and the second conductive field plate comprises polysilicon.
[0703] 29. The BJT of the any one of the above Embodiments, wherein a vertical boundary of the base well is defined by an edge of a layer stack disposed on the second lateral section of the drift region.
[0704] 30. The BJT of the any one of the above Embodiments, wherein the drift region has a lower dopant concentration relative to that of the HD collector region and of the base well.
[0705] 31. The BJT of the any one of the above Embodiments, wherein a vertical boundary of the base well is defined by an edge of a layer stack disposed on a second lateral section of the drift region extending from the base well to the first lateral section of the drift region.
[0706] 32. The BJT of the any one of the above Embodiments, wherein the layer stack is disposed on the thin dielectric layer having a thickness less than a thickness of the thick dielectric layer.
[0707] 33. The BJT of the any one of the above Embodiments, further comprising a fourth conductive field plate above the drift region, the fourth conductive field plate electrically connected to the first, second, and the third conductive field plates.
[0708] 34. The BJT of the any one of the above Embodiments, wherein the third and further conductive field plate comprise metal.
[0709] 35. The BJT of the any one of the above Embodiments, wherein the first, second, third field, and fourth conductive field plates are configured to provide a substantially constant lateral electric field component along the drift region.

EXAMPLE EMBODIMENTS V

[0710] 1. A depletion field effect potential divider (DFE-PD) comprising: [0711] a semiconductor substrate; [0712] a first junction formed over the semiconductor substrate and including a reverse-biased depletion region connected to an input node; [0713] a second junction formed over the semiconductor substrate and connected to an output node, [0714] wherein the first junction and the second junction are coupled to substantially linearly scale a high voltage input signal at the input node to a low voltage output signal at the output node.
[0715] 2. The depletion field effect potential divider of Embodiment 1, wherein the high voltage input signal provides a charge at the input node that is directly coupled from the first junction onto a depletion region of the second junction.
[0716] 3. The depletion field effect potential divider of Embodiment 1, wherein the low voltage output signal scales substantially linearly with the high voltage input signal with a DC offset.
[0717] 4. The depletion field effect potential divider of Embodiment 1, further comprising a gate diffusion region formed between the first junction and the second junction.
[0718] 5. The depletion field effect potential divider of Embodiment 4, further comprising a first gate region, a second gate region, and a lightly doped region connecting the first gate region to the second gate region, wherein a polarity of the lightly doped region and a polarity of the gate diffusion region are the same.
[0719] 6. The depletion field effect potential divider of Embodiment 4, wherein the first junction includes an n-type region, the second junction includes an n-type region, and the gate diffusion region includes a p-type region.
[0720] 7. The depletion field effect potential divider of Embodiment 4, further comprising a metal field plate connected to the gate diffusion region and extending over a region between the first junction and the second junction.
[0721] 8. The depletion field effect potential divider of Embodiment 1, wherein the first junction has a bias of about zero volts.
[0722] 9. The depletion field effect potential divider of Embodiment 1, wherein the second junction has a bias of about zero volts.

[0723] 10. The depletion field effect potential divider of Embodiment 1, wherein a magnitude of the scaling factor between the low voltage output signal and the high voltage input signal is adjustable by a ratio of charge coupling between the first junction and the second junction.
[0724] 11. The depletion field effect potential divider of Embodiment 1, further comprising an oxide layer formed over the semiconductor substrate, wherein the first junction and the second junction are formed in the oxide layer.
[0725] 12. The depletion field effect potential divider of Embodiment 11, wherein the oxide layer includes an intermetal dielectric (IMD) oxide layer.
[0726] 13. The depletion field effect potential divider of Embodiment 1, wherein the high voltage input signal is over 100 volts and the low voltage output signal is less than 10 volts.
[0727] 14. The depletion field effect potential divider of Embodiment 1, wherein the input node includes a first metal contact connected to the first junction, and the output node includes a second metal contact connected to the second junction.
[0728] 15. A method of analog signal translation by a depletion field effect potential divider, the method comprising: [0729] providing a high voltage input signal to a reverse-biased depletion region of a first junction formed over a semiconductor substrate; [0730] outputting a low voltage output signal from a second junction formed over the semiconductor substrate; and [0731] coupling charge from the first junction to the second junction to substantially linearly scale the low voltage output signal in relation to the high voltage input signal.
[0732] 16. The method of Embodiment 15, further comprising any of the features of Embodiments 2 through 14.
[0733] 17. A method of forming a depletion field effect potential divider, the method comprising:
[0734] forming a first junction over a semiconductor substrate, the first junction including a reverse-biased depletion region; [0735] contacting the first junction using a first metal contact to form an input node; [0736] forming a second junction over the semiconductor substrate; and [0737] contacting the second junction using a second metal contact to form an output node; [0738] wherein the first junction and the second junction are charge coupled to provide linear scaling between the input node and the output node.
[0739] 18. The method of Embodiment 17, further comprising forming a gate diffusion region over the semiconductor substrate and between the first junction and the second junction.
[0740] 19. The method of Embodiment 18, further comprising forming a first gate region, forming a second gate region, and forming a lightly doped region connection the first gate region and the second gate region, wherein a polarity of the lightly doped region and a polarity of the gate diffusion region are the same.
[0741] 20. The method of Embodiment 18, wherein the first junction includes an n-type region, the second junction includes an n-type region, and the gate diffusion region includes a p-type region.
[0742] 21. The method of Embodiment 18, further comprising forming a metal field plate connected to the gate diffusion region and extending over a region between the first junction and the second junction.
[0743] 22. The method of Embodiment 17, further comprising forming an oxide layer over the semiconductor substrate, wherein the first junction and the second junction are formed in the oxide layer.
[0744] 23. The method of Embodiment 22, wherein the oxide layer includes an intermetal dielectric (IMD) oxide layer.

EXAMPLE EMBODIMENTS VI

[0745] 1. An integrated circuit (IC) device configured for voltage reduction between an input and an output, the IC device comprising; [0746] an isolated substrate region formed in a semiconductor substrate while being electrically isolated therefrom in vertical and lateral directions, the isolated substrate region having formed therein a plurality of alternatingly doped regions arranged laterally in a lateral direction and alternatingly doped with dopants of opposite types, the alternatingly doped

regions comprising: [0747] an input drift region and an output drift region each doped with a dopant of a first type, wherein the input drift region is connected to the input and the output drift region is connected to the output, [0748] an inter-gate region and a substrate region of the isolated substrate region each doped with a dopant of a second type, wherein the inter-gate region is laterally interposed between the input and output drift regions, and [0749] a heavily doped first gate region formed within the inter-gate region [0750] wherein the input drift region is elongated to have a first lateral length along the lateral direction that is longer than a second lateral length of the inter-gate region by at least a factor of two.

[0751] 2. An integrated circuit (IC) device configured for voltage reduction between an input and an output, the IC device comprising: [0752] an isolated substrate region formed in a substrate while being electrically isolated therefrom in vertical and lateral directions, the isolated substrate region having formed therein a plurality of alternatingly doped regions arranged laterally in a lateral direction and alternatingly doped with dopants of opposite types, the alternatingly doped regions comprising: [0753] an input drift region and an output drift region each doped with a dopant of a first type, wherein the input drift region is connected to the input and the output drift region is connected to the output, and [0754] an inter-gate region and a substrate region of the isolated substrate region each doped with a dopant of a second type, wherein the inter-gate region is laterally interposed between the input and output drift regions, [0755] wherein the inter-gate region has a dopant concentration that is lower than that of the input drift region, the output drift region and the substrate region, and [0756] a heavily doped first gate region formed within the inter-gate region.

[0757] 3. An integrated circuit (IC) device configured for voltage reduction between an input and an output, the IC device comprising: [0758] an isolated substrate region formed in a substrate while being electrically isolated therefrom in vertical and lateral directions, the isolated substrate region having formed therein a plurality of alternatingly doped regions arranged laterally in a lateral direction and alternatingly doped with dopants of opposite types, the alternatingly doped regions comprising: [0759] an input drift region and an output drift region each doped with a dopant of a first type, wherein the input drift region is connected to the input and the output drift region is connected to the output, [0760] an inter-gate region and a substrate region of the isolated substrate region each doped with a dopant of a second type, wherein the inter-gate region is laterally interposed between the input and output drift regions, [0761] a dielectric layer covering the input drift region and at least one conductive field plate extending above the dielectric layer along the lateral direction, and [0762] a heavily doped (HD) first gate region formed within the inter-gate region.

[0763] 4. The IC device of Embodiment 1, further comprising a dielectric layer covering the input drift region, and at least one conductive field plate extending above the dielectric layer along the lateral direction.

[0764] 5. The IC device of Embodiment 1, wherein the inter-gate region has a concentration of the dopant of the second type that is lower than that of the input drift region, the output drift region and the substrate region of the isolated substrate region outside of the alternatingly doped regions.

[0765] 6. The IC device of Embodiment 2, further comprising a dielectric layer covering the input drift region, and one or more conductive field plates extending above the dielectric layer along the lateral direction.

[0766] 7. The IC device of Embodiment 2, wherein the input drift region has a first lateral length along the lateral direction that is longer than a second lateral length of the second doped region by at least a factor of two.

[0767] 8. The IC device of Embodiment 3, wherein the inter-gate region has a concentration of the dopant of the second type that is lower than that of the input drift region, output drift region and of a remaining portion of the isolated substrate region outside of the alternatingly doped regions.

[0768] 9. The IC device of Embodiment 3, wherein the input drift region has a first lateral length

along the lateral direction that is longer than a second lateral length of the second doped region by at least a factor of two.
[0769] 10. The IC device of any one of the above Embodiments, wherein the at least one of the conductive field plates is electrically connected to the first gate region.
[0770] 11. The IC device of any one of the above Embodiments, wherein the at least one of the conductive field plates is electrically connected to the first gate region.
[0771] 12. The IC device of any one of the above Embodiments, further comprising a highly doped (HD) gate contact region formed in the isolated substrate region, the (HD) gate contact region having the same polarity as the first gate region, wherein the substrate region is electrically connected to the first gate region via the gate contact region to serve as a second gate region.
[0772] 13. The IC device of any one of the above Embodiments, wherein the IC device is configured to provide an output voltage greater than one microvolt to the output in response to receiving an input voltage greater than 0.5 volts from the input.
[0773] 14. The IC device of any one of the above Embodiments, wherein the isolated substrate region first and the second junctions are reversed biased.
[0774] 15. The IC device of any one of the above Embodiments, wherein the IC device scales a high voltage input signal provided to the input substantially linearly to a low voltage output signal at least for high voltage input signals within a voltage range determined at least by a doping concentration in the inter-gate region and a lateral length of the integrate region.
[0775] 16. The IC device of any one of the above Embodiments, wherein the substrate comprises silicon.
[0776] 17. The IC device of any one of the above Embodiments, wherein an amplitude or minimum-to-maximum magnitude of the high voltage signal is larger than 80 volts.
[0777] 18. The IC device of any one of the above Embodiments, wherein an amplitude or minimum-to-maximum magnitude of the low voltage signal is smaller than 10 volts.
[0778] 19. The IC device of any one of the above Embodiments, wherein a voltage scaling factor of the IC device is at least 2.
[0779] 20. The IC device of any one of the above Embodiments, wherein the output is electrically connected to an active low voltage device formed on a semiconductor substrate on which the isolated substrate region is formed.
[0780] 21. The IC device of any one of the above Embodiments, wherein at least a region of IC device is co-fabricated with a region of the active low voltage device and during the same fabrication step.
[0781] 22. The IC device of any one of the above Embodiments, wherein the first lateral length (LD) is longer than 0.5 micro meters.
[0782] 23. The IC device of any one of the above Embodiments 1, wherein a voltage drop along the IC device comprises a first voltage drop along the input drift region and a second voltage drop along the inter-gate region, wherein the first voltage drop is determined at least partially by the first length (LD).
[0783] 24. The IC device of any one of the above Embodiments, wherein the second voltage drop along the inter-gate region is determined at least partially by the second length (Lp).
[0784] 25. The IC device of any one of the above Embodiments, wherein the second length (Lp) is determined based at least in part on a majority carrier concentration in the inter-gate region.
[0785] 26. The IC device of any one of the above Embodiments, wherein the at least one conductive field plate comprises doped polysilicon.
[0786] 27. The IC device of any one of the above Embodiments, further comprising a second conductive field plate comprising metal.
[0787] 28. The IC device of any one of the above Embodiments 1, further comprising a thick dielectric layer formed over the input drift region forming an interface with the input drift region.
[0788] 29. The IC device of any one of the above Embodiments, wherein the thick dielectric layer

comprises an oxide.
[0789] 30. The IC device of any one of the above Embodiments, the input comprises a highly doped (HD) input region formed in the input drift region, the HD input region having the same polarity as the input drift region.
[0790] 31. The IC device of any one of the above Embodiments, the input comprises a highly doped (HD) output region formed in the output drift region, the HD output region having the same polarity as the output drift region.
[0791] 33. The IC device of any one of the above Embodiments, wherein a majority carrier concentration or a doping concentration in the inter-gate region is smaller than those of the gate region by at least a factor of 10.
[0792] 34. The IC device of any one of the above Embodiments, further comprising a heavily doped gate contact region formed at a surface of the substrate region of the isolated substrate region, the heavily doped gate contact region configured to be at the same polarity as the heavily doped first gate region, wherein the substrate region is electrically connected to the heavily doped first gate and the heavily doped gate contact region to serve as a second gate region.
[0793] 35. The IC device of any one of the above Embodiments, wherein a voltage reduction factor between the input and the output is at least 2.
[0794] 38. The IC device of any one of the above Embodiments, wherein the isolated substrate region is electrically isolated from other substrate regions by at least one dielectric filled trench and a buried dielectric layer.
[0795] 39. A method of forming a depletion field effect potential divider (DFE-PD) in a semiconductor substrate, wherein the (DFE-PD) is configured to scale a high voltage input signal received from a high voltage node to a low voltage output signal provided to at least one low voltage device, the method comprising: [0796] forming an input drift region extended from a first end to a second end along a lateral direction parallel to a main surface of the substrate, the input drift region having a first length (L.sub.D) along the lateral direction and a first depth along a vertical direction perpendicular to the lateral direction; [0797] forming an inter-gate region extended from the second end to third end along the lateral direction, the inter-gate region having a second length (L.sub.p) along the lateral direction and a second depth along the vertical direction; [0798] forming an output drift region extended from the third end to a fourth end along the lateral direction; and [0799] forming highly doped first gate region formed within the inter-gate region; [0800] electrically connecting the input drift region to the high voltage node and the output drift region is electrically connected to the low voltage device; [0801] wherein the input drift region, the output drift region, the first gate region and the inter-gate region are doped regions, the first input drift region and the output drift regions having the same polarity opposite to a polarity of the inter-gate region and the first gate region; and [0802] wherein a majority carrier concentration or a doping concentration in the inter-gate region is smaller than those of the gate region by at least a factor of 102.
[0803] 40. The method of Embodiment 39, further comprising forming at least one conductive field plate extended above the input drift region along the lateral direction.
[0804] 41. The method of any one of the above Embodiments, wherein the field plate is electrically connected to the first gate region.
[0805] 42. The method of any one of the above Embodiments, wherein forming the input drift region, the output drift region, and the inter-gate region comprises forming the input drift region, the output drift region, and the inter-gate region in a first region of the substrate having the same polarity as the inter-gate region.
[0806] 43. The method of any one of the above Embodiments, further comprising electrically connecting the first to the first gate region.
[0807] 44. The method of any one of the above Embodiments, further comprising forming a highly doped gate contact region having the same polarity as the first gate region, in the first region,

wherein the first region of the substrate is electrically connected to the first gate region via the gate contact region.
[0808] 45. The method of any one of the above Embodiments, wherein depletion field effect potential divider (DFE-PD) is configured to provide an output voltage greater than one microvolt to the low voltage active device in response to receiving an input voltage greater than 0.5 volts from the high voltage node.
[0809] 46. The method of any one of the above Embodiments, wherein the substrates comprises silicon.
[0810] 47. The method of any one of the above Embodiments, wherein at least a region of the low voltage device and the DFE-PD are formed during the same fabrication step.
[0811] 48. The method of any one of the above Embodiments, wherein the first length (L.sub.D) is longer than 0.5 micrometers.
[0812] 49. The method of any one of the above Embodiments, wherein the first length is longer than the first depth at least by a factor 2.
[0813] 50. The method of any one of the above Embodiments, further comprising determining the second length (L.sub.p) based at least in part on the majority carrier concentration in the inter-gate region.
[0814] 51. The method of any one of the above Embodiments, wherein the conductive field plate comprises doped polysilicon.
[0815] 52. The method of any one of the above Embodiments, further comprising forming a second conductive field plate above the conductive field plate wherein the second conductive field plate comprises metal.
[0816] 53. The method of any one of the above Embodiments, further comprising forming a thick dielectric layer formed on the input drift region.
[0817] 54. The method of any one of the above Embodiments, wherein the thick dielectric layer comprises an oxide.
[0818] 55. The method of any one of the above Embodiments, further comprising forming a highly doped input region in the input drift region and electrically connecting the highly doped input region to the high voltage node.
[0819] 56. The method of any one of the above Embodiments, further comprising forming a highly doped output region in the input drift region and electrically connecting the highly doped output region to the low voltage device.
[0820] 57. The method of any one of the above Embodiments, further comprising electrically isolating the low voltage device from the DFE-PD.
[0821] 58. The method of any one of the above Embodiments, further comprising forming at least one dielectric filled trench to electrically isolate first region of the substrate from other regions of the substrate.

EXAMPLE EMBODIMENTS VII

[0822] 1. An integrated circuit (IC) device, comprising: [0823] a metal-oxide-semiconductor (MOS) transistor and a bipolar junction transistor (BJT) formed in a common semiconductor substrate; [0824] the BJT comprising a collector region electrically connected to a high voltage potential divider substrate region in series and physically separated therefrom by an isolation structure; and [0825] the BJT further comprising a layer stack comprising a conductive field plate formed over the collector region.
[0826] 2. An integrated circuit (IC) device, comprising: [0827] a metal-oxide-semiconductor (MOS) transistor and a bipolar junction transistor (BJT) formed in a common semiconductor substrate; and [0828] the BJT comprising a collector region electrically connected to a high voltage potential divider substrate region in series and physically separated therefrom by an isolation structure, [0829] wherein the collector region and the high voltage potential divider substrate region are electrically connected through one or more metallization levels formed above a major

surface of the common semiconductor substrate.
[0830] 3. An integrated circuit (IC) device, comprising: [0831] a metal-oxide-semiconductor (MOS) transistor and a bipolar junction transistor (BJT) formed in a common semiconductor substrate; and [0832] the BJT comprising a collector region electrically connected to a high voltage potential divider substrate region in series and physically separated therefrom by an isolation structure, [0833] wherein the high voltage potential divider substrate region is configured to drop >50% of a combined voltage applied across the BJT and the high voltage potential divider substrate region.
[0834] 4. The IC device of any one of the above Embodiments, wherein in operation, each of the MOS transistor and the BJT is configured to drop 5V or less while the high potential divider substrate region is configured to drop 5-400V.
[0835] 5. The IC device of any one of the above Embodiments, wherein the high voltage potential divider substrate region comprises a major portion that is lightly (N- or P-) doped with a same dopant type as the collector region of the BJT.
[0836] 6. The IC device of any one of the above Embodiments, wherein the isolation structure comprises a shallow trench isolation.
[0837] 7. The IC device of any one of the above Embodiments, wherein a gate stack of the MOS transistor and a layer stack of the BJT comprising a conductive field plate formed over the collector region thereof have one or more corresponding layers having a common physical dimension.
[0838] 8. The IC device of any one of the above Embodiments, wherein a gate stack of the MOS transistor and a layer stack of the BJT comprising a conductive field plate formed over the collector region thereof have corresponding spacer structures formed on sidewalls thereof having a common physical dimension.
[0839] 9. The IC device of any one of the above Embodiments, wherein the MOS transistor and the BJT have implanted diffusion regions having a common implanted dopant profile.
[0840] 10. The IC device of any one of the above Embodiments, wherein the BJT is a lateral BJT having an emitter region, a base region and a collector region that are arranged in a lateral direction parallel to a main surface of a common substrate.
[0841] 11. The IC device of any one of the above Embodiments, wherein a layer stack formed over the collector region of the BJT has a dielectric layer that is co-deposited or co-oxidized with and has a same thickness as a gate dielectric of the MOS transistor.
[0842] 12. The IC device of any one of the above Embodiments, wherein a layer stack formed over the collector region of the BJT has a conducting layer on a dielectric that is co-deposited with and has a same thickness as a gate electrode on a gate dielectric of the MOS transistor.
[0843] 13. The IC device of any one of the above Embodiments, wherein a layer stack formed over the collector region of the BJT extends over the isolation structure.
[0844] 14. The IC device of any one of the above Embodiments, wherein a layer stack formed over the collector region of the BJT in a first direction defines a length of the collector region of the BJT, and wherein a lateral dimension of the gate stack defines a channel length of the MOS transistor in the first direction.
[0845] 15. The IC device of any one of the above Embodiments, wherein a layer stack formed over the collector region of the BJT serves as a reduced surface field (RESURF) plate.
[0846] 16. The IC device of any one of the above Embodiments, wherein a layer stack formed over the collector region of the BJT and a gate stack of the MOS transistor have formed on sidewall surfaces thereof spacers that are co-deposited, co-patterned and co-etched such that the spacer of the BJT and spacer of the MOS transistor have substantially a same lateral dimension.
[0847] 17. The IC device of Embodiment 16, wherein substantially the same lateral dimension is a width at a base region of the spacers.
[0848] 18. The IC device of Embodiment 17, wherein the width at the base region of the spacers define a base length of the BJT and a width of a lightly-doped drain of the MOS transistor.

[0849] 19. The IC device of any one of the above Embodiments, wherein the layer stack of the BJT and the gate stack of the MOS transistor have a same lateral dimension and define one or more implanted diffusion regions for the BJT and the MOS transistor that have a co-implanted dopant profile.
[0850] 20. The IC device of Embodiment 19, wherein the layer stack and the gate stack respectively define one end of a base region of the BJT and one end of a lightly-doped drain (LDD) region of the MOS transistor that are co-implanted.
[0851] 21. The IC device of Embodiment 20, wherein the other end of the base region of the BJT and the other end of the lightly-doped drain (LDD) region of the MOS transistor are defined by a spacer formed on respective sidewalls of the layer stack and the gate stack.
[0852] 22. The IC device of Embodiment 20, wherein the LDD region is an n-doped LDD (NLDD) region of an n-channel MOS transistor (NMOS) that is co-implanted with an n-type base region of a PNP BJT.
[0853] 23. The IC device of Embodiment 20, wherein the LDD region is a p-doped LDD (PLDD) region of a p-channel MOS transistor (PMOS) that is co-implanted with a p-type base region of an NPN BJT.
[0854] 24. The IC device of any one of the above Embodiments, wherein a spacer of the BJT and a spacer of the MOS transistor have a same lateral dimension and define one or more implanted diffusion regions for the BJT and the MOS transistor that have a common implanted dopant profile.
[0855] 25. The IC device of Embodiment 24, wherein the spacer of the BJT and the spacer of the MOS transistor respectively define one end of an emitter region of the BJT and one end of a source/drain (S/D) region of the MOS transistor that are co-implanted.
[0856] 26. The IC device of Embodiment 25, wherein the S/D region is an n-doped S/D of an n-channel MOS transistor (NMOS) that is co-implanted with an n-type emitter region of an NPN BJT.
[0857] 27. The IC device of Embodiment 25, wherein the S/D region is a p-doped S/D of a p-channel MOS transistor (PMOS) that is co-implanted with a p-type emitter region of PNP BJT.
[0858] 28. The IC device of any one of the above Embodiments, wherein a collector region of the BJT and channel region of the MOS transistor are co-implanted.
[0859] 29. The IC device of Embodiment 28, wherein the channel region is an n-doped well region of a p-channel MOS transistor (PMOS) that is co-implanted with an n-type collector region of an NPN BJT.
[0860] 30. The IC device of Embodiment 29, wherein the n-type collector region comprises a lightly doped region that is co-implanted with an n-doped LDD (NLDD) region of an n-channel MOS transistor (NMOS) and an n-type base region of a PNP BJT.
[0861] 31. The IC device of Embodiment 29, wherein the n-type collector region comprises a heavily doped region that is co-implanted with an n-doped S/D region of an n-channel MOS transistor (NMOS) and an n-type emitter region of an NPN BJT.
[0862] 32. The IC device of Embodiment 28, wherein the channel region is a p-doped well region of an n-channel MOS transistor (NMOS) that is co-implanted with a p-type collector region of PNP BJT.
[0863] 33. The IC device of Embodiment 32, wherein the p-type collector region comprises a lightly doped region that is co-implanted with a p-doped LDD (PLDD) region of a p-channel MOS transistor (PMOS) and a p-type base region of an NPN BJT.
[0864] 34. The IC device of Embodiment 32, wherein the p-type collector region comprises a heavily doped region that is co-implanted with a p-doped S/D region of a p-channel MOS transistor (PMOS) and a p-type emitter region of an PNP BJT.
[0865] 35. An integrated circuit (IC) device, comprising: [0866] a metal-oxide-semiconductor (MOS) transistor and a lateral double-diffused metal-oxide-semiconductor (LDMOS) transistor formed in a common semiconductor substrate; and [0867] the LDMOS transistor comprising an

extended drain drift region that is physically separated from a channel region of the LDMOS transistor by an isolation structure, [0868] wherein a gate stack of the MOS transistor and a gate stack of the LDMOS transistor have one or more corresponding layers having a common physical dimension.
[0869] 36. An integrated circuit (IC) device, comprising: [0870] a metal-oxide-semiconductor (MOS) transistor and a lateral double-diffused metal-oxide-semiconductor (LDMOS) transistor formed in a common semiconductor substrate; and [0871] the LDMOS transistor comprising an extended drain drift region that is physically separated from a channel region of the LDMOS transistor by an isolation structure, [0872] wherein the MOS transistor and the LDMOS transistor have implanted diffusion regions having a common implanted dopant profile.
[0873] 37. An integrated circuit (IC) device, comprising: [0874] a metal-oxide-semiconductor (MOS) transistor and a lateral double-diffused metal-oxide-semiconductor (LDMOS) transistor formed in a common semiconductor substrate; and [0875] the LDMOS transistor comprising an extended drain drift region that is physically separated from a channel region of the LDMOS transistor by an isolation structure, [0876] wherein the extended drain drift region comprises a conductive field plate formed thereover.
[0877] 38. The IC device of any one of the Embodiments 35-37, wherein in operation, the MOS transistor is configured to drop 5V or less while the extended drain drift region is configured to drop 5-400V.
[0878] 39. The IC device of any one of the Embodiment 35-38, wherein the isolation structure comprises a shallow trench isolation.
[0879] 40. The IC device of any one of the Embodiment 35-39, wherein the channel region of the LDMOS transistor and the extended drain drift region are electrically connected through one or more metallization levels formed above a major surface of the common semiconductor substrate.
[0880] 41. IC device of any one of the Embodiment 35-40, wherein the extended drain drift region comprises a major portion that is lightly (N- or P-) doped with a same dopant type as the a source region of the LDMOS transistor.
[0881] 42. IC device of any one of the Embodiment 35-41, wherein the channel of the LDMOS transistor is laterally interposed between a first heavily (N.sup.++ or P.sup.++) doped region serving as a source and a second heavily (N.sup.++ or P.sup.++) doped region doped with the same dopant type as the first heavily doped region.
[0882] 43. IC device of any one of the Embodiment 35-42, wherein the second heavily (N.sup.++ or P.sup.++) doped region is physically separated by the isolation structure from, while being electrically connected to, a third heavily (N.sup.++ or P.sup.++) doped region formed in the extended drain drift region and doped with the same dopant type as the first and second heavily doped regions.
[0883] 44. IC device of any one of the Embodiment 35-43, wherein the extended drain drift region comprises a conductive field plate formed thereover to serve as a reduced surface field (RESURF) plate.
[0884] 45. IC device of any one of the Embodiment 35-44, wherein the LDMOS transistor comprises a backgate contact electrically connected to a conductive field plate formed over the extended drain drift region serving as a reduced surface field (RESURF) plate.
[0885] 46. IC device of any one of the Embodiment 35-45, wherein the LDMOS transistor comprises a backgate contact electrically connected to a heavily (N.sup.++ or P.sup.++) doped region formed in and oppositely doped as a major portion of the extended drain drift region that is lightly (N- or P-) doped.
[0886] 47. IC device of any one of the Embodiment 35-46, wherein a gate dielectric of the LDMOS transistor is co-deposited or co-oxidized with and has a same thickness as a gate dielectric of the MOS transistor.
[0887] 48. IC device of any one of the Embodiment 35-47, wherein a gate electrode of the LDMOS

is co-deposited and co-patterned with and has a same thickness as a gate electrode of the MOS transistor.
[0888] 49. IC device of any one of the Embodiment 35-48, wherein the extended drain drift region comprises a conductive field plate formed thereover to serve as a reduced surface field (RESURF) plate that is co-deposited with and has a same thickness as a gate electrode of one or both of the MOS transistor and the LDMOS transistor.
[0889] 50. IC device of any one of the Embodiment 35-49, wherein a gate stack of the LDMOS transistor and a gate stack of the MOS transistor are co-patterned to have a same lateral dimension in at least one direction.
[0890] 51. IC device of any one of the Embodiment 35-50, wherein a lateral dimension of a gate stack defines a channel length of one or both of the MOS transistor and the LDMOS transistor.
EXAMPLE EMBODIMENTS VIII
[0891] 1. An integrated circuit (IC) device, comprising: [0892] at least one low voltage active semiconductor device formed in a first substrate region of a semiconductor substrate; and [0893] a depletion field effect potential divider (DFE-PD) formed in a second substrate region of the semiconductor substrate and configured to reduce a high voltage input signal received from a high voltage node to generate a low voltage output signal, and to provide the low voltage output signal to the low voltage active semiconductor device as an input signal thereto, [0894] wherein the low voltage active semiconductor device and the DFE-PD are physically separated while being electrically connected in series, and [0895] wherein the first and the second substrate regions are electrically separated by an isolation structure.
[0896] 2. An integrated circuit (IC) device, comprising: [0897] at least one low voltage active semiconductor device formed in a first substrate region of a semiconductor substrate; and [0898] a depletion field effect potential divider (DFE-PD) formed in a second substrate region of the semiconductor substrate and configured to reduce a high voltage input signal received from a high voltage node to generate a low voltage output signal, and to provide the low voltage output signal to the low voltage active semiconductor device as an input signal thereto, [0899] wherein the DFE-PD comprises a plurality of alternatingly doped regions arranged laterally in a lateral direction and alternatingly doped with dopants of opposite types, the alternatingly doped regions comprising: [0900] an input drift region and an output drift region each doped with a dopant of a first type, wherein the input drift region is connected to the input and the output drift region is connected to the output, [0901] an inter-gate region laterally interposed between the input and output drift regions, wherein the inter-gate region and the second substrate region are doped with a dopant of a second type, and [0902] a heavily doped first gate region formed within the inter-gate region.
[0903] 3. The integrated circuit (IC) device of any one of the above Embodiments, wherein the at least one low voltage active semiconductor device comprises a bipolar junction transistor (BJT).
[0904] 4. The integrated circuit (IC) device of any one of the above Embodiments, wherein the BJT is a lateral BJT having an emitter region, a base region and a collector region that are arranged in a lateral direction parallel to a major surface of a common substrate.
[0905] 5. The integrated circuit (IC) device of any one of the above Embodiments, wherein the BJT is a lateral BJT having a layer stack comprising a reduced surface field (RESURF) layer formed over a collector region.
[0906] 6. The integrated circuit (IC) device of any one of the above Embodiments, wherein the at least one low voltage active semiconductor device comprises a metal oxide semiconductor (MOS) transistor having a gate stack comprising a gate layer formed over a channel region.
[0907] 7. The integrated circuit (IC) device of any one of the above Embodiments, wherein the at least one low voltage active semiconductor further comprises a lateral BJT having an emitter region, a base region and a collector region that are arranged in a lateral direction parallel to a main surface of a common substrate.
[0908] 8. The integrated circuit (IC) device of any one of the above Embodiments, wherein the gate

stack of the MOS transistor and the layer stack of the lateral BJT have one or more corresponding layers having a common physical dimension.

[0909] 9. The integrated circuit (IC) device of any one of the above Embodiments, wherein the gate stack of the MOS transistor and the layer stack of the lateral BJT comprise corresponding spacer structures formed on sidewalls thereof, the corresponding spacer structures having a common physical dimension.

[0910] 10. The integrated circuit (IC) device of any one of the above Embodiments, wherein a width of a base portion of the spacers define a base length of the lateral BJT and a width of a lightly-doped drain of the MOS transistor.

[0911] 11. The integrated circuit (IC) device of any one of the above Embodiments, wherein the lateral BJT further comprises a layer stack comprising a dielectric layer between a reduced surface field (RESURF) layer and the base region that is co-deposited or co-oxidized with and has a same thickness as a gate dielectric layer of the MOS transistor.

[0912] 12. The integrated circuit (IC) device of any one of the above Embodiments, wherein the at least one low voltage semiconductor active device and the DFE-PD are electrically connected through one or more metallization levels formed above a major surface of the semiconductor substrate.

[0913] 13. The integrated circuit (IC) device of any one of the above Embodiments, wherein in operation, the at least one low voltage semiconductor active device is configured to drop 5V or less while the DFE-PD is configured to drop 5-400V.

[0914] 14. The integrated circuit (IC) device of any one of the above Embodiments, wherein the isolation structure comprises a shallow or deep dielectric filed trench.

[0915] 15. The integrated circuit (IC) device of any one of the above Embodiments, wherein the isolation structure further comprises a buried dielectric layer.

[0916] 16. The integrated circuit (IC) device of any one of the above Embodiments, wherein the DFE-PD is configured to reduce the high voltage input signal by at least 50%.

[0917] 17. The integrated circuit (IC) device of any one of the above Embodiments, wherein the input drift region is elongated to have a first lateral length along the lateral direction that is longer than a second lateral length of the inter-gate region by at least a factor of two.

[0918] 18. The integrated circuit (IC) device of any one of the above Embodiments, wherein the inter-gate region has a dopant concentration that is lower than that of the input drift region, the output drift region and the second substrate region.

[0919] 19. The integrated circuit (IC) device of any one of the above Embodiments, further comprising at least one conductive field plate extending above the input drift region along the lateral direction.

[0920] 20. The integrated circuit (IC) device of any one of the above Embodiments, wherein the at least one low voltage active semiconductor device comprises one or both of a metal oxide semiconductor transistor or a bipoloar junction transistor.

[0921] 23. The integrated circuit (IC) device of any one of the above Embodiments, wherein the BJT is a lateral BJT (L-BJT) having a layer stack comprising a RESURF layer formed over a collector region.

[0922] 24. The integrated circuit (IC) device of any one of the above Embodiments, wherein the at least one low voltage active semiconductor device comprises a MOS transistor having a gate stack comprising a gate layer formed over a channel region.

[0923] 25. The integrated circuit (IC) device of any one of the above Embodiments, wherein the at least one low voltage active semiconductor device comprises a MOS transistor having a gate stack comprising a gate layer formed over a channel region, and a lateral BJT (L-BJT) having a layer stack comprising a RESURF layer formed over a collector region, the L-BJT having an emitter region, a base region and a collector region that are arranged in a lateral direction parallel to a main surface of a common substrate.

[0924] 26. The integrated circuit (IC) device of any one of the above Embodiments, wherein the gate stack of the MOS transistor and the layer stack of the L-BJT have one or more corresponding layers having a common physical dimension.
[0925] 27. The integrated circuit (IC) device of any one of the above Embodiments, wherein the gate stack of the MOS transistor and the layer stack of the L-BJT comprise spacer structures formed on sidewalls of the layer stack and the gate stack, the spacer structures having a common physical dimension.
[0926] 28. The integrated circuit (IC) device of any one of the above Embodiments, wherein the width at the base region of the spacers define a base length of the BJT and a width of a lightly-doped drain of the MOS transistor.
[0927] 29. The integrated circuit (IC) device of any one of the above Embodiments 8, wherein the MOS transistor and the L-BJT have implanted diffusion regions having a common implanted dopant profile.
[0928] 30. The integrated circuit (IC) device of any one of the above Embodiments, wherein the layer stack formed has a RESURF dielectric layer that is co-deposited or co-oxidized with and has a same thickness as a gate dielectric layer of the MOS transistor.
[0929] 31. The integrated circuit (IC) device of any one of the above Embodiments, wherein the layer stack and the gate stack respectively define one end of a base region of the BJT and one end of a lightly-doped drain region of the MOS transistor that are co-implanted.
[0930] 34. The integrated circuit (IC) device of any one of the above Embodiments, wherein the isolation structure comprises a shallow dielectric filed trench.
[0931] 35. The integrated circuit (IC) device of any one of the above Embodiments, wherein the isolation structure comprises a deep dielectric filed trench.
[0932] 36. The integrated circuit (IC) device of any one of the above Embodiments, wherein the isolation structure comprises a buried dielectric layer.
[0933] 37. The integrated circuit (IC) device of any one of the above Embodiments, wherein the DFE-PD is configured to reduce the high voltage input signal by at least 50%.
[0934] 38. The integrated circuit (IC) device of any one of the above Embodiments, wherein the DFE-PD comprises a major portion that is lightly (N- or P-) doped with a same dopant type as the collector region of the BJT or a drain region of the MOS transistor.
[0935] 39. The integrated circuit (IC) device of any one of the above Embodiments, wherein the DFE-PD comprises: [0936] an input drift region extended from a first end to a second end along a lateral direction parallel to the main surface of the substrate, the input drift region having a first length (LD) along the lateral direction; [0937] an inter-gate region extended from the second end to third end along the lateral direction, the inter-gate region having a second length (Lp) along the lateral direction; [0938] an output drift region extended from the third end to a fourth end along the lateral direction; and [0939] a highly doped first gate region formed within the inter-gate region; [0940] wherein the first length is larger than the second length and the first depth; [0941] wherein the first input drift region and the second drift regions have the same polarity opposite to a polarity of the inter-gate region and the first gate region; and [0942] wherein a majority carrier concentration or a doping concentration in the inter-gate region is smaller than those of the gate region by at least a factor of 10.
[0943] 40. The integrated circuit (IC) device of any one of the above Embodiments, further comprising at least one conductive field plate extended above the input drift region along the lateral direction.
[0944] 41. The integrated circuit (IC) device of any one of the above Embodiments, wherein the field plate is electrically connected to the first gate region.
[0945] 42. The integrated circuit (IC) device of any one of the above Embodiments, wherein the first region of the substrate having the same polarity as the inter-gate region.
[0946] 43. The integrated circuit (IC) device of any one of the above Embodiments, wherein the

second substrate region is electrically connected to the first gate region and at least a portion of the second substrate region serves as a second gate region for the DFE-PD.
[0947] 44. The integrated circuit (IC) device of any one of the above Embodiments, wherein the first length (LD) is longer than 0.5 micrometers.
[0948] 45. The integrated circuit (IC) device of any one of the above Embodiments, wherein the second length (Lp) is shorter than 5.0 micrometers.
[0949] 46. The integrated circuit (IC) device of any one of the above Embodiments, wherein the first length (LD) is longer than the second length (Lp) at least by a factor 2.
EXAMPLE EMBODIMENTS IX
[0950] 1. An integrated circuit (IC) device, comprising: [0951] a metal-oxide-semiconductor (MOS) transistor and one or both of a bipolar junction transistor (BJT) and a lateral double-diffused metal-oxide-semiconductor (LDMOS) transistor formed in a common silicon substrate; and [0952] a high voltage potential divider region formed above a major surface of the common semiconductor substrate and integrated in a back-end-of-line (BEOL) of the IC device, [0953] wherein the high voltage potential divider region is formed of a wide bandgap semiconductor material.
[0954] 2. An integrated circuit (IC) device, comprising: [0955] a metal-oxide-semiconductor (MOS) transistor and one or both of a bipolar junction transistor (BJT) and a lateral double-diffused metal-oxide-semiconductor (LDMOS) transistor formed in a common silicon substrate; and [0956] a high voltage potential divider region formed above a major surface of the common semiconductor substrate and integrated in a back-end-of-line (BEOL) of the IC device, [0957] wherein the high voltage potential divider region comprises a major portion comprising a lightly doped semiconductor region.
[0958] 3. An integrated circuit (IC) device, comprising: [0959] a metal-oxide-semiconductor (MOS) transistor and one or both of a bipolar junction transistor (BJT) and a lateral double-diffused metal-oxide-semiconductor (LDMOS) transistor formed in a common silicon substrate; and [0960] a high voltage potential divider region formed above a major surface of the common semiconductor substrate and integrated in a back-end-of-line (BEOL) of the IC device, wherein in operation, the high voltage potential divider region is configured to drop a higher voltage relative to at least the MOS transistor.
[0961] 4. The IC device of any one of the above Embodiments, wherein in operation, each of the MOS transistor and the BJT is configured to drop 5V or less while the high voltage potential divider region is configured to drop 5-400V.
[0962] 5. The IC device of any one of the above Embodiments, wherein the high voltage potential divider region is separated from the major surface of the common semiconductor substrate by at least one intermetal dielectric layer.
[0963] 6. The IC device of any one of the above Embodiments, wherein the high voltage potential divider region is embedded in an intermetal dielectric layer.
[0964] 7. The IC device of any one of the above Embodiments, wherein the high voltage potential divider region comprises a major portion comprising a lightly (N- or P-) doped semiconductor region laterally extending between heavily doped regions, wherein one of the heavily doped regions is connected to the one or both of the BJT and the LDMOS transistor and the other one of the heavily doped regions is configured as a high voltage input configured to be biased at 5-400V.
[0965] 8. The IC device of any one of the above Embodiments, wherein the high voltage potential divider region comprises a conductive field plate formed thereover to serve as a reduced surface field (RESURF) plate.
[0966] 9. The IC device of any one of the above Embodiments, wherein the high voltage potential divider region is formed of a wide band gap semiconductor comprising one or more of SiC, GaN and Ga.sub.2O.sub.3.
[0967] 10. The IC device of any one of the above Embodiments, wherein the IC device comprises

the BJT, and wherein a collector region of the BJT is electrically connected to the high voltage potential divider region in series.
[0968] 11. The IC device of Embodiment 10, wherein the BJT is a lateral BJT and comprises a layer stack formed over a collector region thereof.
[0969] 12. The IC device of Embodiment 11, wherein a gate stack of the MOS transistor and the layer stack of the BJT have at least one layer having a common physical dimension.
[0970] 13. The IC device of Embodiment 11, wherein a gate stack of the MOS transistor and the layer stack of the BJT each have spacer structures formed on respective sidewalls thereof and having a common physical dimension.
[0971] 14. The IC device of Embodiment 11, wherein the MOS transistor and the BJT have implanted diffusion regions having a common implanted dopant profile.
[0972] 15. The IC device of any one of the above Embodiments, wherein the IC device comprises the LDMOS, and wherein a channel region of the LDMOS is electrically connected to the high voltage potential divider region in series.
[0973] 16. The IC device of Embodiment 15, wherein the high voltage potential divider region serves as an extended drain drift region of the LDMOS that is physically separated from a channel region of the LDMOS.
[0974] 17. The IC device of Embodiment 15, wherein a gate stack of the MOS transistor and a gate stack of the LDMOS transistor have at least one layer having a common physical dimension.
[0975] 18. The IC device of Embodiment 13, wherein the MOS transistor and the LDMOS transistor have implanted diffusion regions having a common implanted dopant profile.
EXAMPLE EMBODIMENTS X
[0976] 1. An integrated circuit (IC) device, comprising: [0977] at least one low voltage active device formed in a semiconductor substrate; and [0978] a depletion field effect potential divider (DFE-PD) formed above a major surface of the semiconductor substrate and separated therefrom by a dielectric layer, the DFE-PD configured to scale a high voltage input signal received from a high voltage node to a low voltage output signal, and to provide a low voltage signal to the low voltage active device as an input signal thereto, the DFE-PD comprising: [0979] a doped semiconductor region extending along a lateral direction parallel to the major surface of the substrate between a heavily doped (HD) input region and a heavily doped (HD) output region, and [0980] a depletion control region formed within the doped semiconductor region and oppositely doped relatively to a remainder of the doped semiconductor region; [0981] wherein the DFE-PD and the low voltage active device are electrically connected by an electrical connection.
[0982] 2. An integrated circuit (IC) device, comprising: [0983] at least one low voltage active device formed in a semiconductor substrate; and [0984] a depletion field effect potential divider (DFE-PD) formed above a major surface of the semiconductor substrate and separated therefrom by a dielectric layer, the DFE-PD configured to scale a high voltage input signal received from a high voltage node to a low voltage output signal, and to provide a low voltage signal to the low voltage active device as an input signal thereto, the DFE-PD comprising: [0985] a doped semiconductor region laterally extending along a lateral direction parallel to the major surface of the substrate between a heavily doped (HD) input region that receives the low voltage output signal and a heavily doped (HD) output region that outputs the low voltage signal, [0986] a depletion control region formed within the doped semiconductor region and oppositely doped relatively to a remainder of the doped semiconductor region, and [0987] at least one conductive field plate laterally extending over the doped semiconductor region and electrically connected to the low voltage active device by an electrical connection formed at least partly above the semiconductor substrate.
[0988] 3. The IC device of Embodiment 1, wherein the DFE-PD further comprises at least one conductive field plate laterally extending over the doped semiconductor region and electrically connected to the low voltage active device by an electrical connection formed above the

semiconductor substrate by one or more common metallization levels of the low voltage active device and the DFE-PD.
[0989] 4. The IC device of Embodiment 2, wherein the DFE-PD and the low voltage active device are electrically connected by an electrical connection formed by one or more common metallization levels of the low voltage active device and the DFE-PD.
[0990] 5. The integrated circuit (IC) device of an one of the above Embodiments, wherein DFE-PD further comprises an input drift region extending between the HD input region and the depletion control region, and an output drift region extending between the depletion control region and the output drift region.
[0991] 6. The integrated circuit (IC) device of any one of the above Embodiments, a thicknesses of the depletion control region, the input drift region, and the output drift region along a vertical direction are substantially equal, and are smaller than 2 micrometers, wherein vertical direction is perpendicular to the lateral direction.
[0992] 7. The integrated circuit (IC) device of any one of the above Embodiments, further comprising a second conductive field plate laterally extended above the at least one field plate and electrically connected to the first field plate.
[0993] 8. The integrated circuit (IC) device of any one of the above Embodiments, wherein depletion field effect potential divider (DFE-PD) is configured to provide an output voltage greater than one microvolt to the low voltage active device in response to receiving an input voltage greater than 0.5 volts from the high voltage node.
[0994] 9. The integrated circuit (IC) device of any one of the above Embodiments, wherein a length of the input drift region along the lateral direction is at least 2 times larger than a length of the depletion control region.
[0995] 10. The integrated circuit (IC) device of any one of the above Embodiments, wherein the dielectric layer comprises a buried dielectric layer within the substrate.
[0996] 11. The integrated circuit (IC) device of any one of the above Embodiments, wherein the dielectric layer is formed on the semiconductor substrate.
[0997] 12. The integrated circuit (IC) device of any one of the above Embodiments, wherein a region of the semiconductor substrate below the dielectric layer is electrically connected to the HD output region and serves as a field plate for the DFE-PD, and wherein the region of the semiconductor substrate has the same polarity as the HD output region.
[0998] 13. The integrated circuit (IC) device of any one of the above Embodiments, wherein a region of the semiconductor substrate below the dielectric layer is electrically connected to the at least one conductive field plate via an HD contact region and serves as a second field plate for the DFE-PD, and wherein the region of the semiconductor substrate and the HD contact region have the same polarity as the depletion control region.
[0999] 14. The integrated circuit (IC) device of any one of the above Embodiments, wherein a pn junction and a dielectric layer are formed between the region of the semiconductor substrate and a region of the substrate on which the low voltage device is formed.
[1000] 15. The integrated circuit (IC) device of any one of the above Embodiments, wherein the dielectric layer comprises a cladding dielectric layer disposed on the semiconductor substrate.
[1001] 16. The integrated circuit (IC) device of any one of the above Embodiments, wherein the dielectric layer comprises an intermetal dielectric layer (IDL).
[1002] 17. The integrated circuit (IC) device of any one of the above Embodiments, wherein the dielectric layer comprises a cladding dielectric layer disposed on the semiconductor substrate and the DFE-PD is integrated in a back-end-of-line (BEOL) of the IC device,
[1003] 18. The integrated circuit (IC) device of any one of the above Embodiments, wherein the dielectric layer comprises a cladding dielectric layer disposed on the semiconductor substrate, wherein the high voltage potential divider region is embedded in an intermetal dielectric layer (IMD).

[1004] 19. The integrated circuit (IC) device of any one of the above Embodiments, wherein the IC device further comprises a second field plate disposed on a second dielectric layer formed on the semiconductor substrate, the second field plate electrically connected to the low voltage device and eth at least one field plate.
[1005] 20. The integrated circuit (IC) device of any one of the above Embodiments, wherein an amplitude or minimum-to-maximum magnitude of the high voltage input signal is larger than 80 volts.
[1006] 21. The integrated circuit (IC) device of any one of the above Embodiments, wherein an amplitude or minimum-to-maximum magnitude of the low voltage output signal is less than 5 volts.
[1007] 22. The integrated circuit (IC) device of any one of the above Embodiments, wherein the at least one low voltage active device comprises a lateral BJT or a MOS transistor.
[1008] 23. The integrated circuit (IC) device of any one of the above Embodiments, comprising a second low voltage active device, wherein the at least one of the low voltage active device comprises a BJT and the second low voltage active device comprises a MOS transistor.
[1009] 24. The integrated circuit (IC) device of any one of the above Embodiments, wherein the BJT comprises an L-BJT and a layer stack of the L-BJT and a gate stack of the MOS transistor have at least one layer having a common physical dimension.
[1010] 25. The integrated circuit (IC) device of any one of the above Embodiments, wherein the L-BJT comprises a laterally extended base region having a length defined by a spacer disposed on a side wall of the layer stack.
[1011] 26. The integrated circuit (IC) device of any one of the above Embodiments, wherein the spacer has the same physical dimensions and is co-fabricated with another spacer dispose on a side wall of the gate stack.
[1012] 27. The integrated circuit (IC) device of any one of the above Embodiments, wherein the L-BJT and the MOS transistor have at least one implanted region having a common implanted dopant profile.
[1013] 28. The integrated circuit (IC) device of any one of the above Embodiments, wherein in operation, the low voltage active device is configured to drop 5V or less while the DFE-PD is configured to drop 5-400V.
[1014] 29. The integrated circuit (IC) device of any one of the above Embodiments, wherein the doped semiconductor region comprises at least one wide bandgap semiconductor material.
[1015] 30. The integrated circuit (IC) device of any one of the above Embodiments, wherein the DFE-PD comprises at least one of SiC, GaN and Ga.sub.2O.sub.3.
[1016] 31. The integrated circuit (IC) device of any one of the above Embodiments, wherein a majority carrier concentration or a doping concentration in the inter-gate region is smaller than those of the gate region by at least a factor of 10.
[1017] 32. The integrated circuit (IC) device of any one of the above Embodiments, wherein DFE-PD further comprises an input drift region extending between the HD input region and the depletion control region, and an output drift region extending between the depletion control region and the HD output region, the input and output drift regions having a doping concentration less than that of the HD input and output regions.
[1018] 35. The integrated circuit (IC) device of any one of the above Embodiments, wherein the HD output region is electrically connected to the low voltage active device by a common metallization levels of the low voltage active device and the DFE-PD.
[1019] 37. The integrated circuit (IC) device of any one of the above Embodiments, wherein a region of the semiconductor substrate below the dielectric layer is electrically connected to the at least one conductive field plate via a heavily doped contact region, formed in the semiconductor substrate, and serves as a second field plate for the DFE-PD, and wherein the region of the semiconductor substrate and the HD contact region have the same polarity as the depletion control

region.
[1020] 38. A method of fabricating an integrated circuit (IC) device, the method comprising: [1021] forming at least one low voltage device on a semiconductor substrate; and [1022] forming a depletion field effect potential divider (DFE-PD) above a major surface of substrate and on a dielectric layer, the DFE-PD configured to scale a high voltage input signal received from a high voltage node to a low voltage output signal provided the low voltage device, forming the DFE-PD comprising: [1023] forming a doped semiconductor region laterally extended in a lateral direction parallel to the main surface of the substrate between a highly doped (HD) input region and a highly doped (HD) output region, the doped semiconductor region comprising a depletion control region laterally extended from an input doped region to an output doped region of the doped semiconductor region; and [1024] electrically connecting the HD input region to the high voltage node and the HD output region to the low voltage device; [1025] wherein the input drift region, the output drift region, the HD input region, and the HD output region have the same polarity opposite to a polarity of the depletion control region; and [1026] wherein a majority carrier concentration or a doping concentration in the depletion control region is smaller than those of the input and output drift regions by at least a factor of 10.
[1027] 39. The method of Embodiment 38, wherein a thicknesses of the depletion control region, the input drift region, and the output drift region along a vertical direction are substantially equal and smaller than 2.0 micrometers, wherein vertical direction is perpendicular to the lateral direction.
[1028] 40. The method of any one of the above Embodiments, further comprising forming a first conductive field plate extended above the input drift region along the lateral direction and electrically connecting it to a reduced surface field (RESURF) layer or a gate layer of the low voltage device, the field plate serving as a RESURF plate for the DFE-PD.
[1029] 41. The method of any one of the above Embodiments, further comprising forming a second conductive field plate laterally extended above the first field plate and electrically connected to the first field plate.
[1030] 42. The method of any one of the above Embodiments, wherein depletion field effect potential divider (DFE-PD) is configured to provide an output voltage greater than one microvolt to the low voltage active device in response to receiving an input voltage greater than 0.5 volts from the high voltage node.
[1031] 43. The method of any one of the above Embodiments, wherein a length of the input drift region along the lateral direction is at least 2 times larger than a length of the depletion control region. Valid
[1032] 44. The method of any one of the above Embodiments, wherein the dielectric layer comprises a buried dielectric layer within the substrate.
[1033] 45. The method of any one of the above Embodiments, wherein the dielectric layer is formed on the semiconductor substrate.
[1034] 46. The method of any one of the above Embodiments, further comprising electrically connecting a region of the semiconductor substrate below the dielectric layer to the HD output region, wherein the region of the semiconductor substrate has the same polarity as the HD output region.
[1035] 47. The method of any one of the above Embodiments, further comprising electrically connecting a region of the semiconductor substrate below the dielectric layer to a first field plate above the input drift region via an HD contact region, and wherein the region of the semiconductor substrate and the HD contact region have the same polarity as the depletion control region.
[1036] 48. The method of any one of the above Embodiments, further comprising forming a PN junction and a dielectric layer between the region of the semiconductor substrate and a region of the substrate on which the low voltage device is formed.
[1037] 49. The method of any one of the above Embodiments, wherein the dielectric layer

comprises a cladding dielectric layer disposed on the semiconductor substrate.
[1038] 50. The method of any one of the above Embodiments, wherein forming the DFE-PD comprises forming the DFE-PD above a major surface of the semiconductor substrate and integrating in a back-end-of-line (BEOL) of the IC device.
[1039] 51. The method of any one of the above Embodiments, wherein the DFE-PD is separated from the major surface of the semiconductor substrate by at least one intermetal dielectric layer.
[1040] 52. The method of any one of the above Embodiments, wherein forming the DFE-PD comprises embedding the DFE-PD in an intermetal dielectric layer.
[1041] 53. The method of any one of the above Embodiments, further comprising forming first field plate on a second dielectric layer formed on the semiconductor substrate, and electrically connecting the first field plate to the low voltage device and a second field plate over the input drift region.
[1042] 54. The method of any one of the above Embodiments, wherein an amplitude or minimum-to-maximum magnitude of the high voltage input signal is larger than 100 volts.
[1043] 55. The method of any one of the above Embodiments, wherein an amplitude or minimum-to-maximum magnitude of the low voltage output signal is less than 5 volts. Perfect
[1044] 56. The method of any one of the above Embodiments, wherein the low voltage device comprises a lateral BJT or a MOS transistor.
[1045] 57. The method of any one of the above Embodiments, further comprising forming a second low voltage device on the semiconductor substrate, wherein the at least one low voltage device comprises a BJT and the second low voltage device comprises a MOS transistor.
[1046] 58. The method of any one of the above Embodiments, wherein the BJT comprises an L-BJT and a layer stack of the L-BJT and a gate stack of the MOS transistor have at least one layer having a common physical dimension.
[1047] 59. The method of any one of the above Embodiments, wherein the L-BJT comprises a laterally extended base region having a length defined by a spacer disposed on a side wall of the layer stack.
[1048] 60. The method of any one of the above Embodiments, wherein the spacer has the same physical dimensions and is co-fabricated with another spacer dispose on a side wall of the gate stack.
[1049] 61. The method of any one of the above Embodiments, wherein the L-BJT and the MOS transistor have at least one implanted region having a common implanted dopant profile.
[1050] 62. The method of any one of the above Embodiments, wherein in operation, the low voltage device is configured to drop 5V or less while the high voltage potential divider region is configured to drop 5-400V.
[1051] 63. The method of any one of the above Embodiments, wherein forming the DFE-PD comprises forming the DFE-PD by deposing or growing at least one wide bandgap semiconductor material.
[1052] 64. The method of any one of the above Embodiments, wherein the at least one wide bandgap semiconductor material region comprises SiC, GaN and Ga.sub.2O.sub.3.
Terminology
[1053] In the foregoing, it will be appreciated that any feature of any one of the embodiments can be combined or substituted with any other feature of any other one of the embodiments.
[1054] Aspects of this disclosure can be implemented in various electronic devices. Examples of the electronic devices can include, but are not limited to, consumer electronic products, parts of the consumer electronic products, electronic test equipment, cellular communications infrastructure such as a base station, etc. Examples of the electronic devices can include, but are not limited to, a mobile phone such as a smart phone, a wearable computing device such as a smart watch or an ear piece, a telephone, a television, a computer monitor, a computer, a modem, a hand-held computer, a laptop computer, a tablet computer, a personal digital assistant (PDA), a microwave, a refrigerator,

a vehicular electronics system such as an automotive electronics system, a stereo system, a DVD player, a CD player, a digital music player such as an MP3 player, a radio, a camcorder, a camera such as a digital camera, a portable memory chip, a washer, a dryer, a washer/dryer, peripheral device, a clock, etc. Further, the electronic devices can include unfinished products.

[1055] The foregoing description may refer to elements or features as being “connected” or “coupled” together. As used herein, unless expressly stated otherwise, “connected” means that one element/feature is directly or indirectly connected to another element/feature, and not necessarily mechanically. Likewise, unless expressly stated otherwise, “coupled” means that one element/feature is directly or indirectly coupled to another element/feature, and not necessarily mechanically. Thus, although the various schematics shown in the figures depict example arrangements of elements and components, additional intervening elements, devices, features, or components may be present in an actual embodiment (assuming that the functionality of the depicted circuits is not adversely affected).

[1056] As used herein, unless expressly stated otherwise, “similar” or “substantially identical means”, depending on the variability of the process, can be +/−5%, +/−10%, etc.

[1057] While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the disclosure. Indeed, the novel apparatus, methods, and systems described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the methods and systems described herein may be made without departing from the spirit of the disclosure. For example, while the disclosed embodiments are presented in a given arrangement, alternative embodiments may perform similar functionalities with different components and/or circuit topologies, and some elements may be deleted, moved, added, subdivided, combined, and/or modified. Each of these elements may be implemented in a variety of different ways. Any suitable combination of the elements and acts of the various embodiments described above can be combined to provide further embodiments.

[1058] Unless the context clearly requires otherwise, throughout the description and the claims, the words “comprise,” “comprising,” “include,” “including” and the like are to be construed in an inclusive sense, as opposed to an exclusive or exhaustive sense; that is to say, in the sense of “including, but not limited to.” The word “coupled”, as generally used herein, refers to two or more elements that may be either directly connected, or connected by way of one or more intermediate elements. Likewise, the word “connected”, as generally used herein, refers to two or more elements that may be either directly connected, or connected by way of one or more intermediate elements. Additionally, the words “herein,” “above,” “below,” and words of similar import, when used in this application, shall refer to this application as a whole and not to any particular portions of this application. Where the context permits, words in the above Detailed Description using the singular or plural number may also include the plural or singular number, respectively. The word “or” in reference to a list of two or more items, that word covers all of the following interpretations of the word: any of the items in the list, all of the items in the list, and any combination of the items in the list.

[1059] Moreover, conditional language used herein, such as, among others, “can,” “could,” “might,” “may,” “e.g.,” “for example,” “such as” and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or states. Thus, such conditional language is not generally intended to imply that features, elements and/or states are in any way required for one or more embodiments or whether these features, elements and/or states are included or are to be performed in any particular embodiment.

[1060] While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the disclosure. Indeed, the novel apparatus, methods, and systems described herein may be embodied in a variety of other forms;

furthermore, various omissions, substitutions and changes in the form of the methods and systems described herein may be made without departing from the spirit of the disclosure. For example, while blocks are presented in a given arrangement, alternative embodiments may perform similar functionalities with different components and/or circuit topologies, and some blocks may be deleted, moved, added, subdivided, combined, and/or modified. Each of these blocks may be implemented in a variety of different ways. Any suitable combination of the elements and acts of the various embodiments described above can be combined to provide further embodiments. The various features and processes described above may be implemented independently of one another, or may be combined in various ways. All possible combinations and subcombinations of features of this disclosure are intended to fall within the scope of this disclosure.

Claims

1. An integrated circuit (IC) device configured for voltage reduction between an input and an output, the IC device comprising: an isolated substrate region formed in a semiconductor substrate while being electrically isolated therefrom in vertical and lateral directions, the isolated substrate region having formed therein a plurality of alternatingly doped regions arranged laterally in a lateral direction and alternatingly doped with dopants of opposite types, the alternatingly doped regions comprising: an input drift region and an output drift region each doped with a dopant of a first type, wherein the input drift region is connected to the input and the output drift region is connected to the output, an inter-gate region and a substrate region of the isolated substrate region each doped with a dopant of a second type, wherein the inter-gate region is laterally interposed between the input and output drift regions, and a heavily doped first gate region formed within the inter-gate region, wherein the input drift region is elongated to have a first lateral length along the lateral direction that is longer than a second lateral length of the inter-gate region by at least a factor of two.
2. The IC device of claim 1, further comprising a dielectric layer covering the input drift region, and at least one conductive field plate extending above the dielectric layer along the lateral direction.
3. The IC device of claim 1, wherein the inter-gate region has a concentration of the dopant of the second type that is lower than that of the input drift region, the output drift region and the substrate region of the isolated substrate region outside of the alternatingly doped regions.
4. The IC device of claim 2, wherein the at least one conductive field plate is electrically connected to the heavily doped first gate region.
5. The IC device of claim 1, further comprising a heavily doped gate contact region formed at a surface of the substrate region of the isolated substrate region, the heavily doped gate contact region configured to be at the same polarity as the heavily doped first gate region, wherein the substrate region is electrically connected to the heavily doped first gate region and the heavily doped gate contact region to serve as a second gate region.
6. The IC device of claim 1, wherein the IC device is configured to provide an output voltage greater than one microvolt to the output in response to receiving an input voltage greater than 0.5 volts from the input.
7. The IC device of claim 1, wherein a voltage reduction factor between the input and the output is at least 2.
8. An integrated circuit (IC) device configured for voltage reduction between an input and an output, the IC device comprising: an isolated substrate region formed in a substrate while being electrically isolated therefrom in vertical and lateral directions, the isolated substrate region having formed therein a plurality of alternatingly doped regions arranged laterally in a lateral direction and alternatingly doped with dopants of opposite types, the alternatingly doped regions comprising: an input drift region and an output drift region each doped with a dopant of a first type, wherein the

input drift region is connected to the input and the output drift region is connected to the output, and an inter-gate region and a substrate region of the isolated substrate region each doped with a dopant of a second type, wherein the inter-gate region is laterally interposed between the input and output drift regions, wherein the inter-gate region has a dopant concentration that is lower than that of the input drift region, the output drift region and the substrate region, and a heavily doped first gate region formed within the inter-gate region.

9. The IC device of claim 8, further comprising a dielectric layer covering the input drift region, and one or more conductive field plates extending above the dielectric layer along the lateral direction.

10. The IC device of claim 8, wherein the input drift region has a first lateral length along the lateral direction that is longer than a second lateral length of the inter-gate region by at least a factor of two.

11. The IC device of claim 9, wherein at least one of the conductive field plates is electrically connected to the heavily doped first gate region.

12. The IC device of claim 8, further comprising a heavily doped gate contact region formed at a surface of the substrate region of the isolated substrate region, the heavily doped gate contact region configured to be at the same polarity as the heavily doped first gate region, wherein the substrate region is electrically connected to the heavily doped first gate region and the heavily doped gate contact region to serve as a second gate region.

13. The IC device of claim 8, wherein the IC device is configured to provide an output voltage greater than one microvolt to the output in response to receiving an input voltage greater than 0.5 volts from the input.

14. An integrated circuit (IC) device configured for voltage reduction between an input and an output, the IC device comprising; an isolated substrate region formed in a substrate while being electrically isolated therefrom in vertical and lateral directions, the isolated substrate region having formed therein a plurality of alternatingly doped regions arranged laterally in a lateral direction and alternatingly doped with dopants of opposite types, the alternatingly doped regions comprising: an input drift region and an output drift region each doped with a dopant of a first type, wherein the input drift region is connected to the input and the output drift region is connected to the output, an inter-gate region and a substrate region of the isolated substrate region each doped with a dopant of a second type, wherein the inter-gate region is laterally interposed between the input and output drift regions, a dielectric layer covering the input drift region and at least one conductive field plate extending above the dielectric layer along the lateral direction, and a heavily doped (HD) first gate region formed within the inter-gate region.

15. The IC device of claim 14, wherein the inter-gate region has a concentration of the dopant of the second type that is lower than that of the input drift region, output drift region and of a remaining portion of the isolated substrate region outside of the alternatingly doped regions.

16. The IC device of claim 14, wherein the input drift region has a first lateral length along the lateral direction that is longer than a second lateral length of the inter-gate region by at least a factor of two.

17. The IC device of claim 14, wherein the at least one conductive field plate is electrically connected to the heavily doped first gate region.

18. The IC device of claim 14, further comprising a heavily doped gate contact region formed at a surface of the substrate region of the isolated substrate region, the heavily doped gate contact region configured to be at the same polarity as the heavily doped first gate region, wherein the substrate region is electrically connected to the heavily doped first gate region and the heavily doped gate contact region to serve as a second gate region.

19. The IC device of claim 14, wherein the IC device is configured to provide an output voltage greater than one microvolt to the output in response to receiving an input voltage greater than 0.5 volts from the input.

20. The IC device of claim 14, wherein the isolated substrate region is electrically isolated from other substrate regions by at least one dielectric filled trench and a buried dielectric layer.