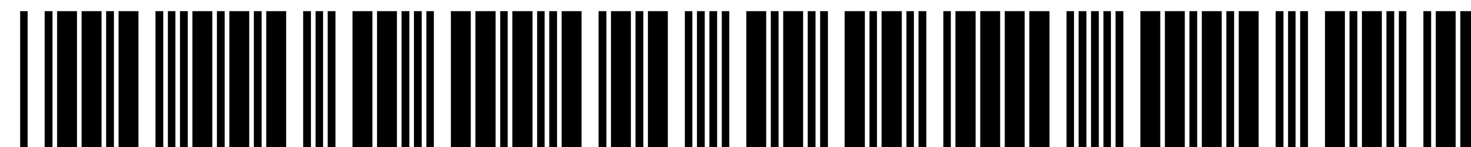
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(45) **Date of Reissued Patent: Jan. 28, 2014**

(54) **METHOD OF MANUFACTURING A MOSFET STRUCTURE**

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(21) Appl. No.: **13/235,000**

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Issued: **Mar. 30, 2010**
Appl. No.: **12/058,507**
Filed: **Mar. 28, 2008**

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(51) **Int. Cl.**
H01L 21/331 (2006.01)
H01L 21/337 (2006.01)

(52) **U.S. Cl.**
USPC **438/309**; 438/186; 438/195; 438/286; 438/279; 257/343; 257/493; 257/288; 257/E27.051; 257/E21.427; 257/E21.421; 257/E21.422

(58) **Field of Classification Search**
USPC 438/309, 301, 303, 282, 299, 237, 328, 438/519, 521, 172, 180, 185, 188, 191, 208, 438/220, 230, 231, 305, 197, 306, 223, 224, 438/227, 228, 298, 234, 186, 289, 302, 286, 438/279, 195; 257/343, 493, 288, E27.051, 257/E27.017, E21.022, E21.039, E27.016, 257/E29.76, E29.94, E31.062, E31.113, 257/E31.119, E21.421, E21.422
See application file for complete search history.

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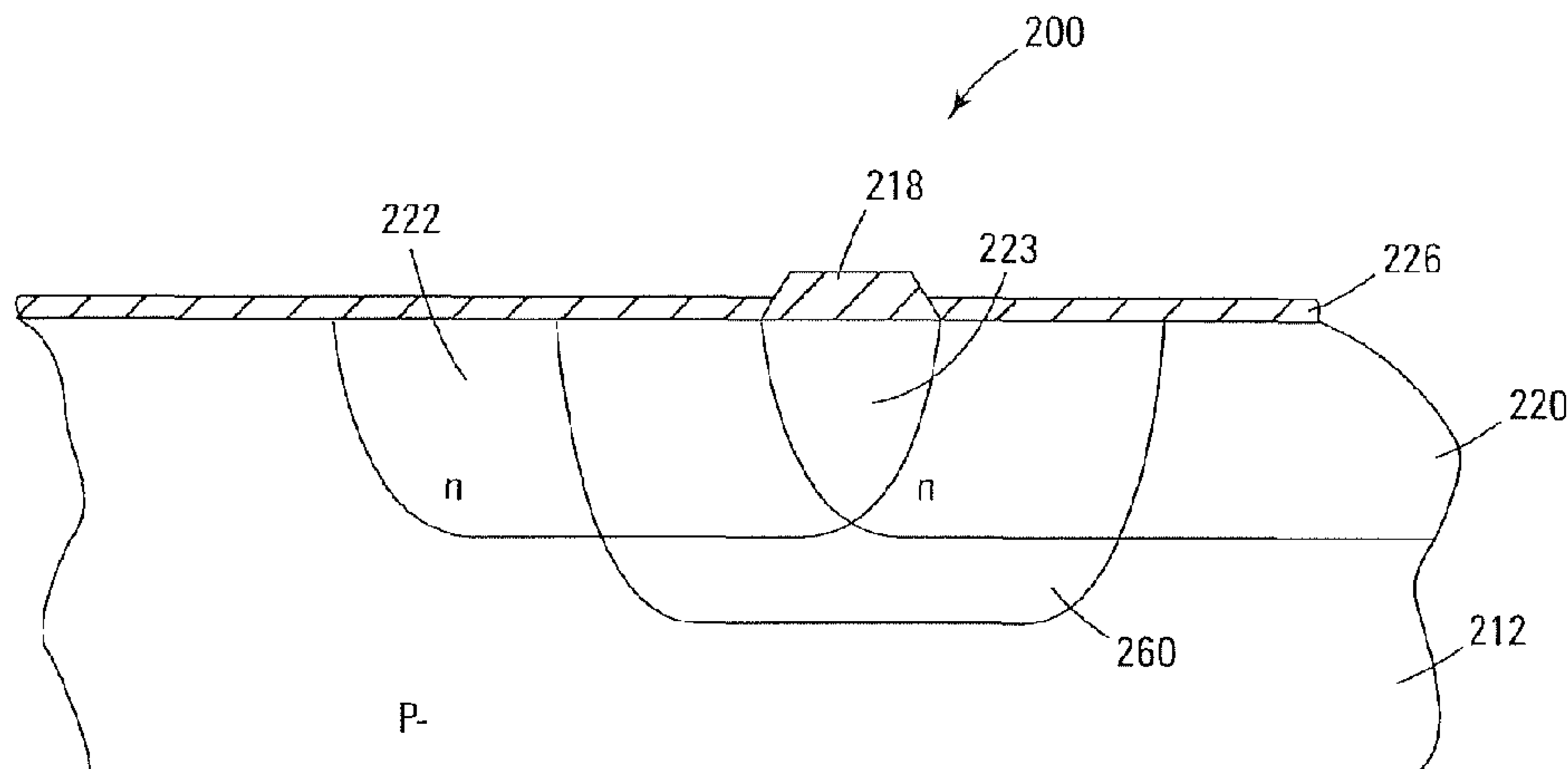
Primary Examiner — Chuong A Luu
(74) *Attorney, Agent, or Firm* — Fogg & Powers LLC

(57) **ABSTRACT**

A method of forming a MOSFET is provided. The method comprises forming a relatively thin layer of dielectric on a substrate. Depositing a gate material layer on the relatively thin layer of dielectric. Removing portions of the gate material layer to form a first and second gate material regions of predetermined lateral lengths. Introducing a first conductivity type dopant in the substrate to form a top gate using first edges of the first and second gate material regions as masks, Introducing a second conductivity dopant of high dopant density in the substrate to form a drain region adjacent the surface of the substrate using a second edge of the second gate material region as a mask to form a first edge of the drain region, wherein a spaced distance between the top gate and the drain region is determined by the lateral length of the second gate material region.

15 Claims, 27 Drawing Sheets



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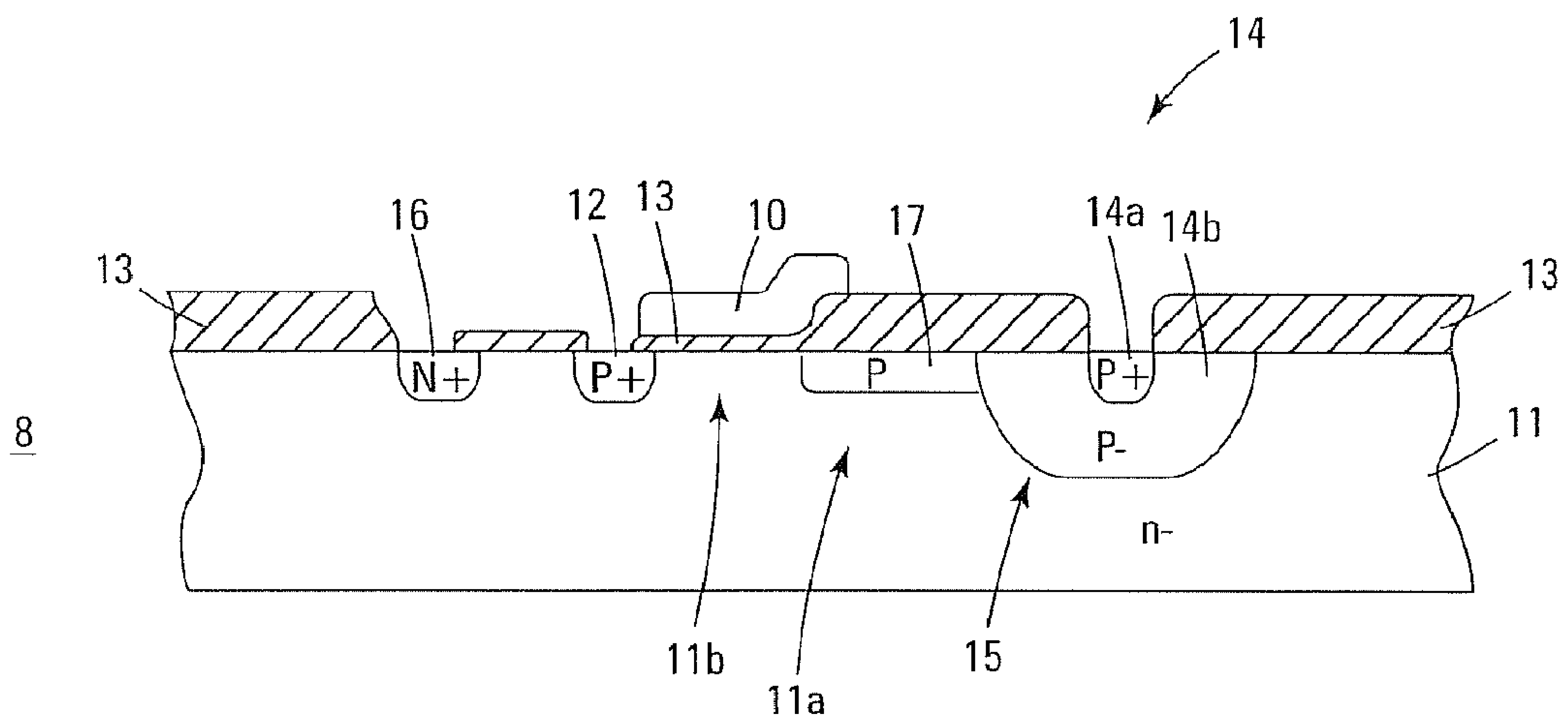

Fig. 1
(Prior Art)

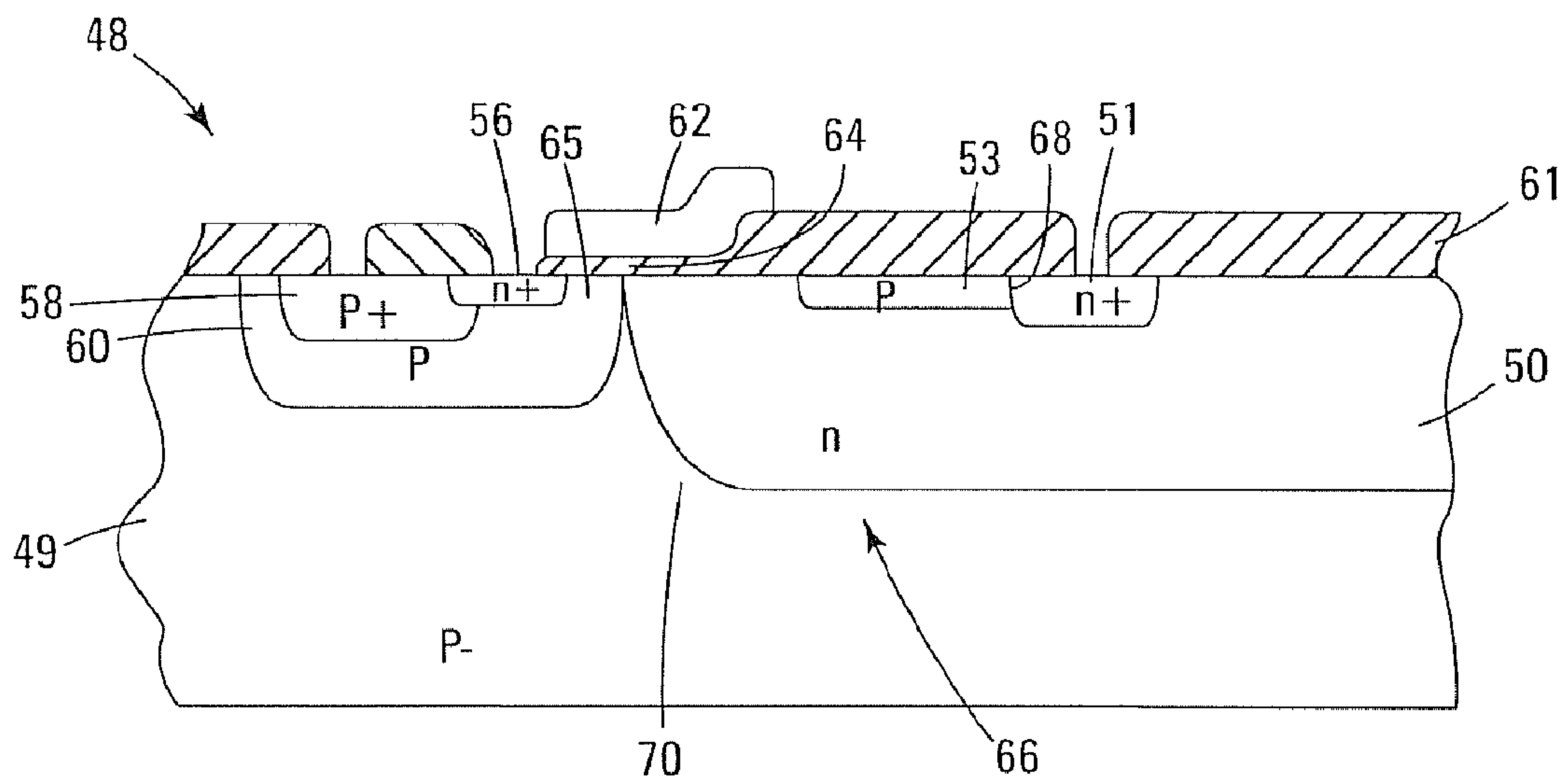

Fig. 2
(Prior Art)

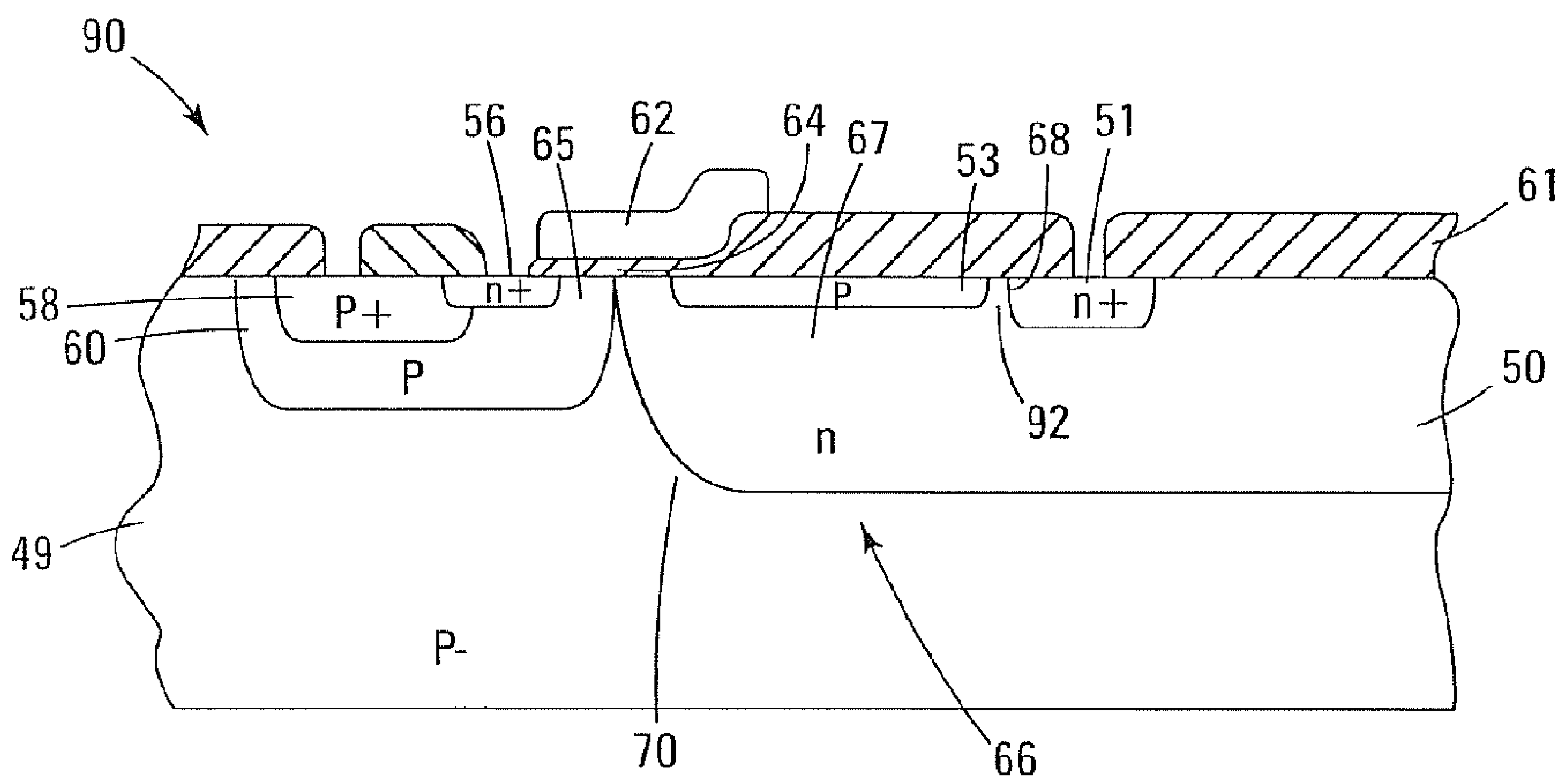

Fig. 3
(Prior Art)

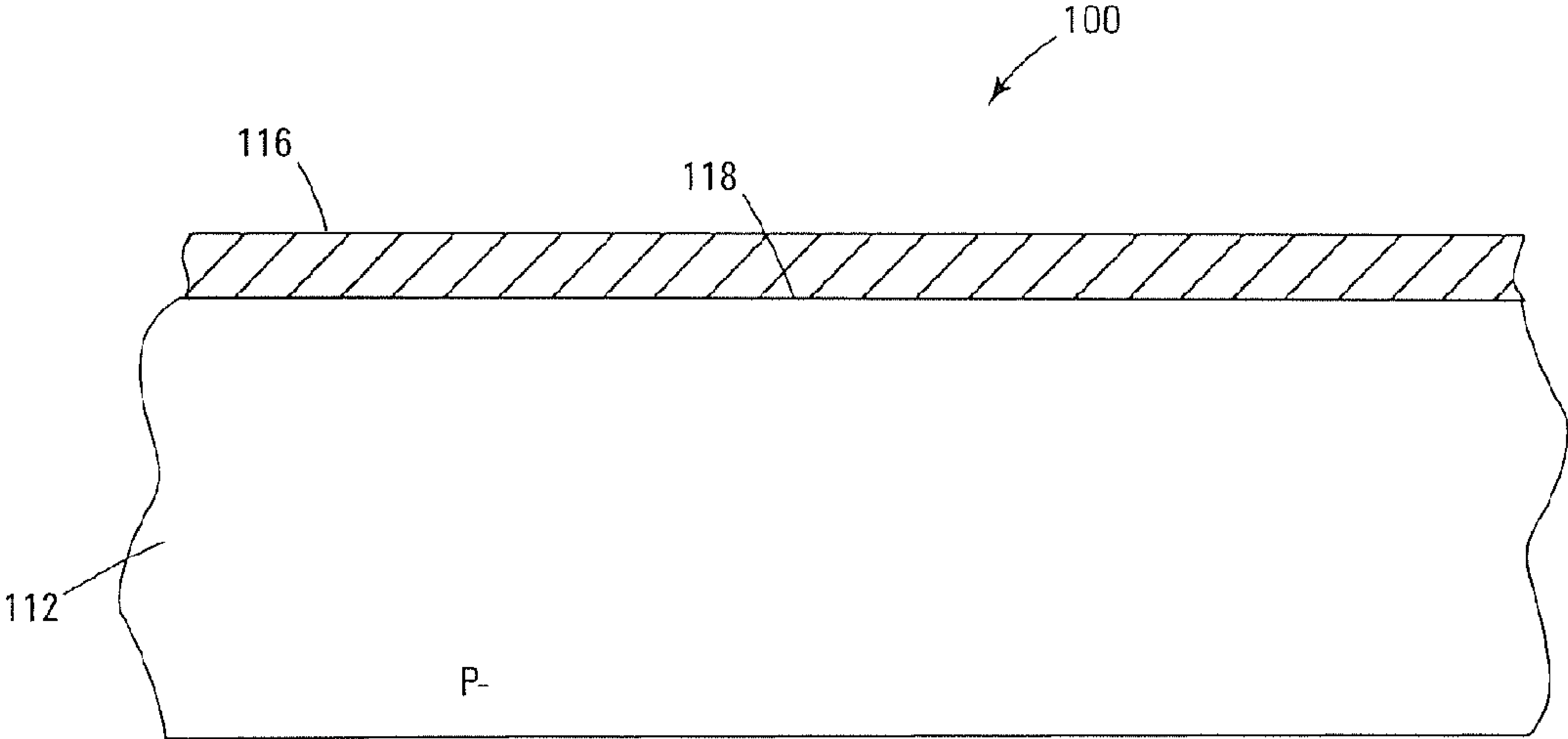

Fig. 4

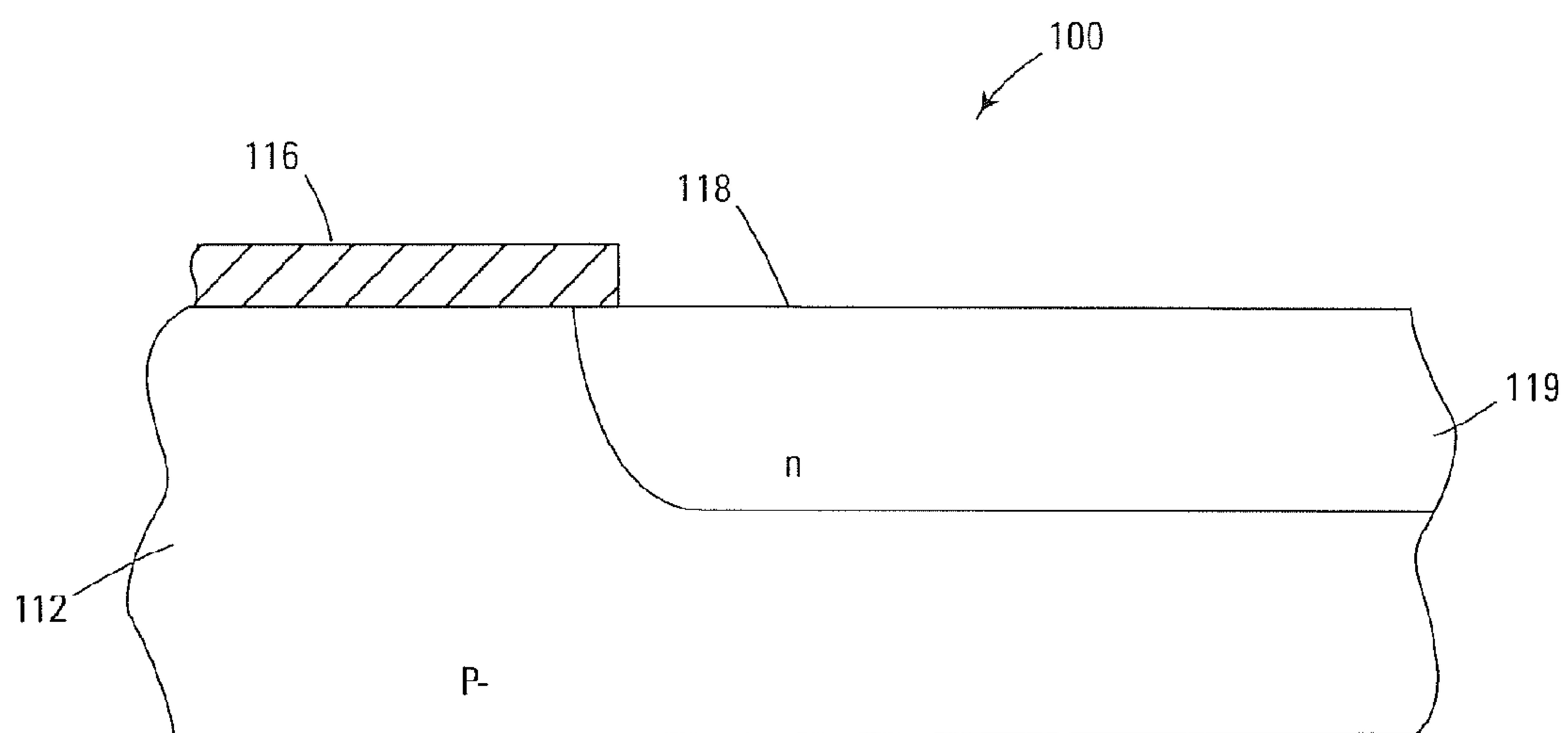

Fig. 5

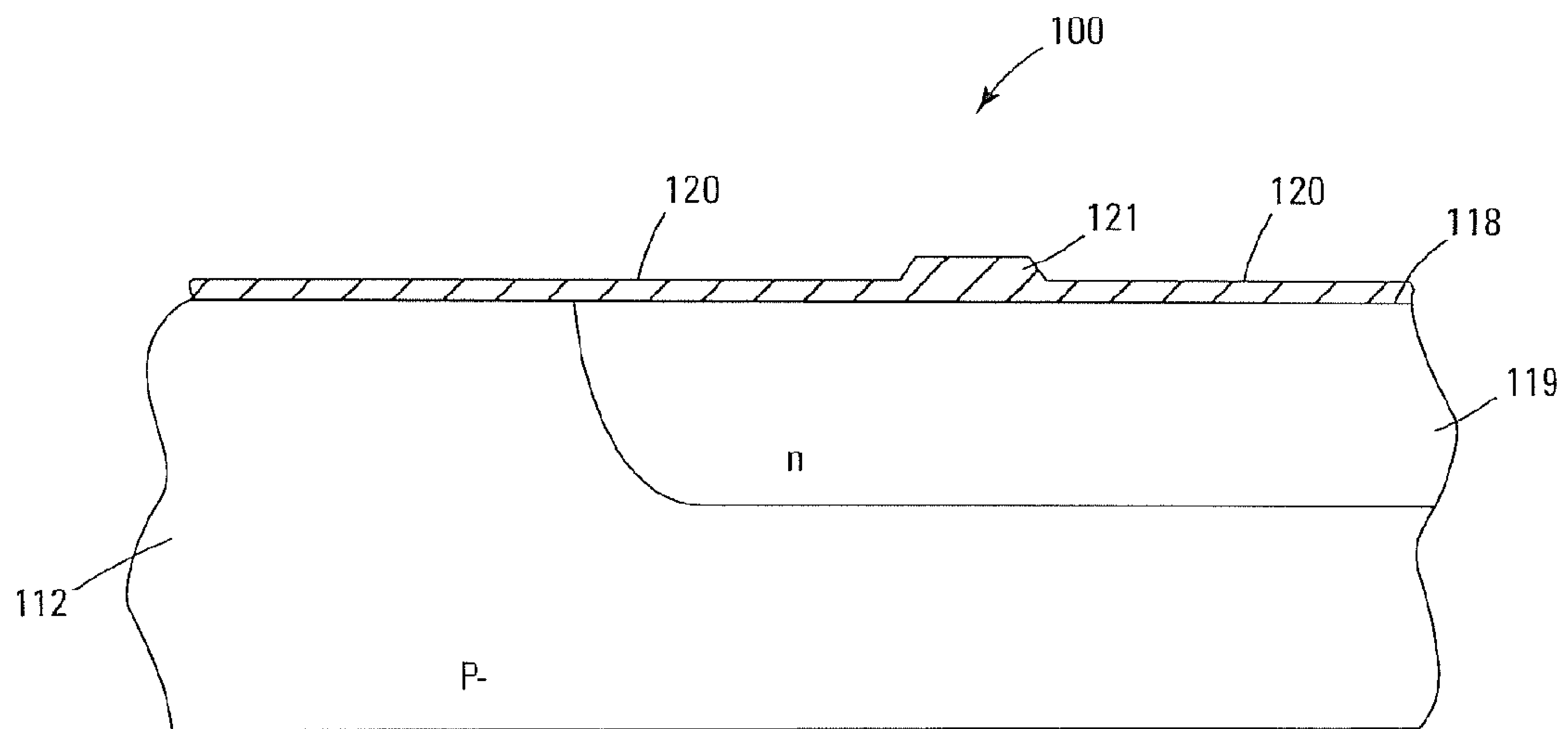

Fig. 6

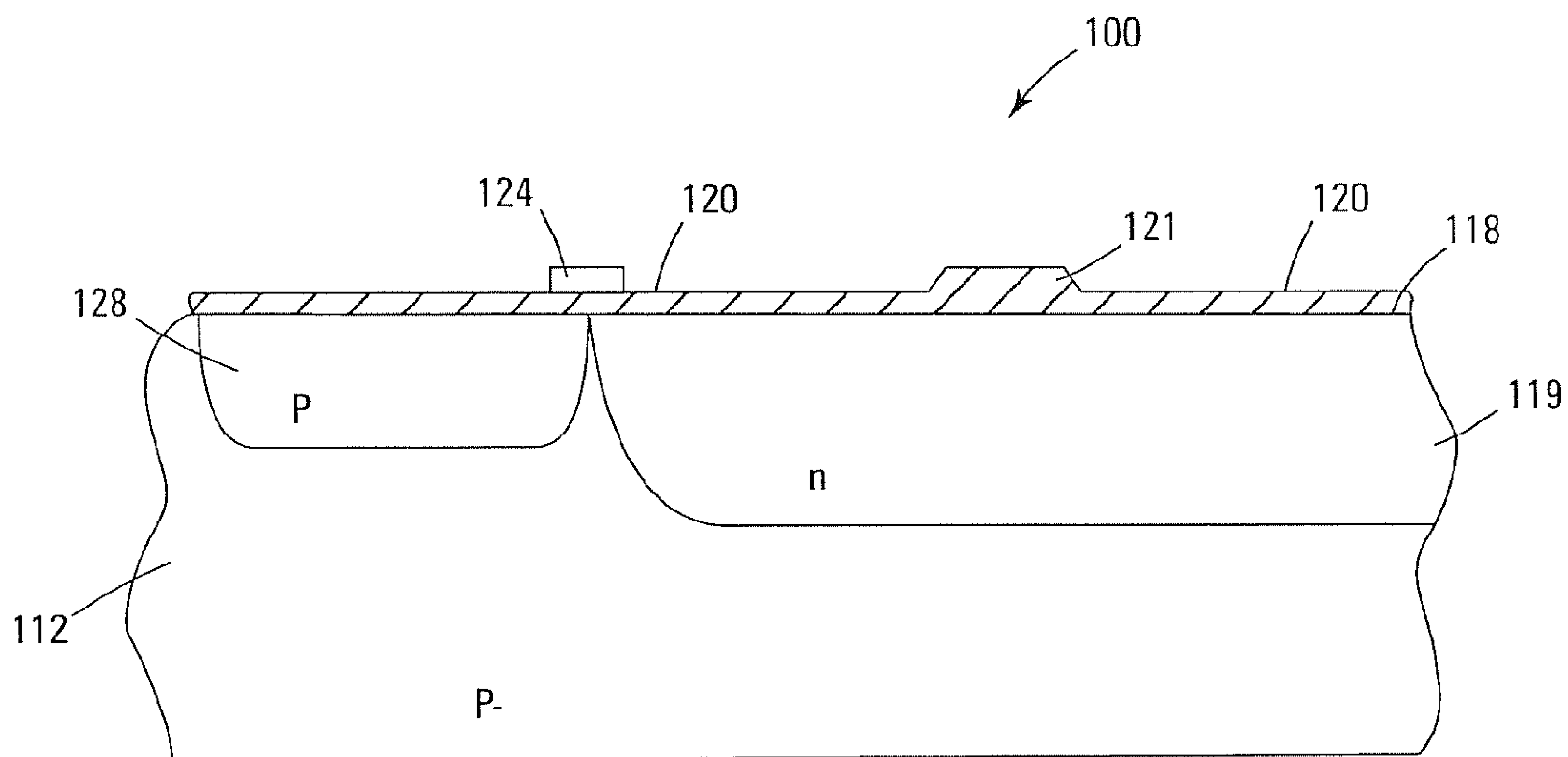

Fig. 7

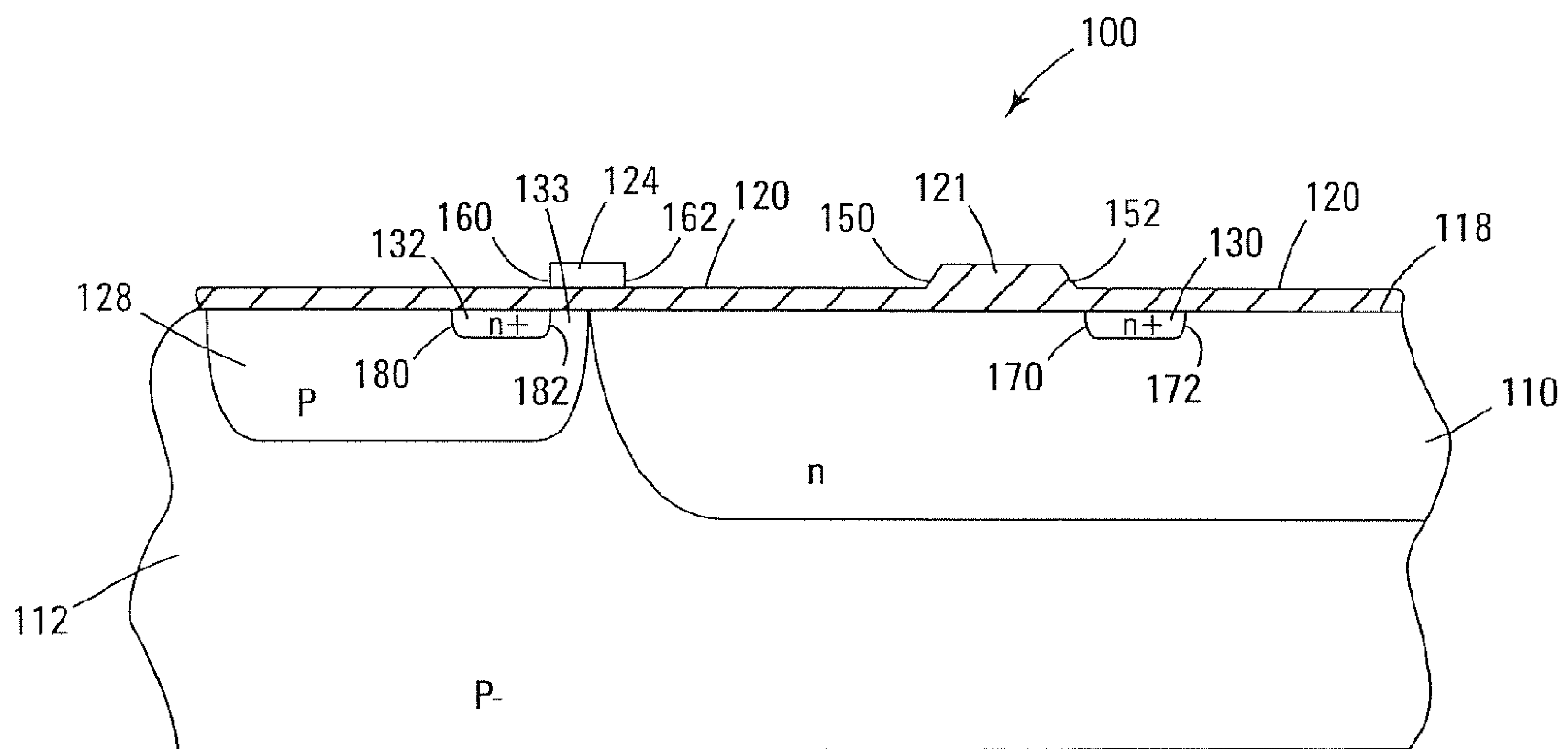

Fig. 8

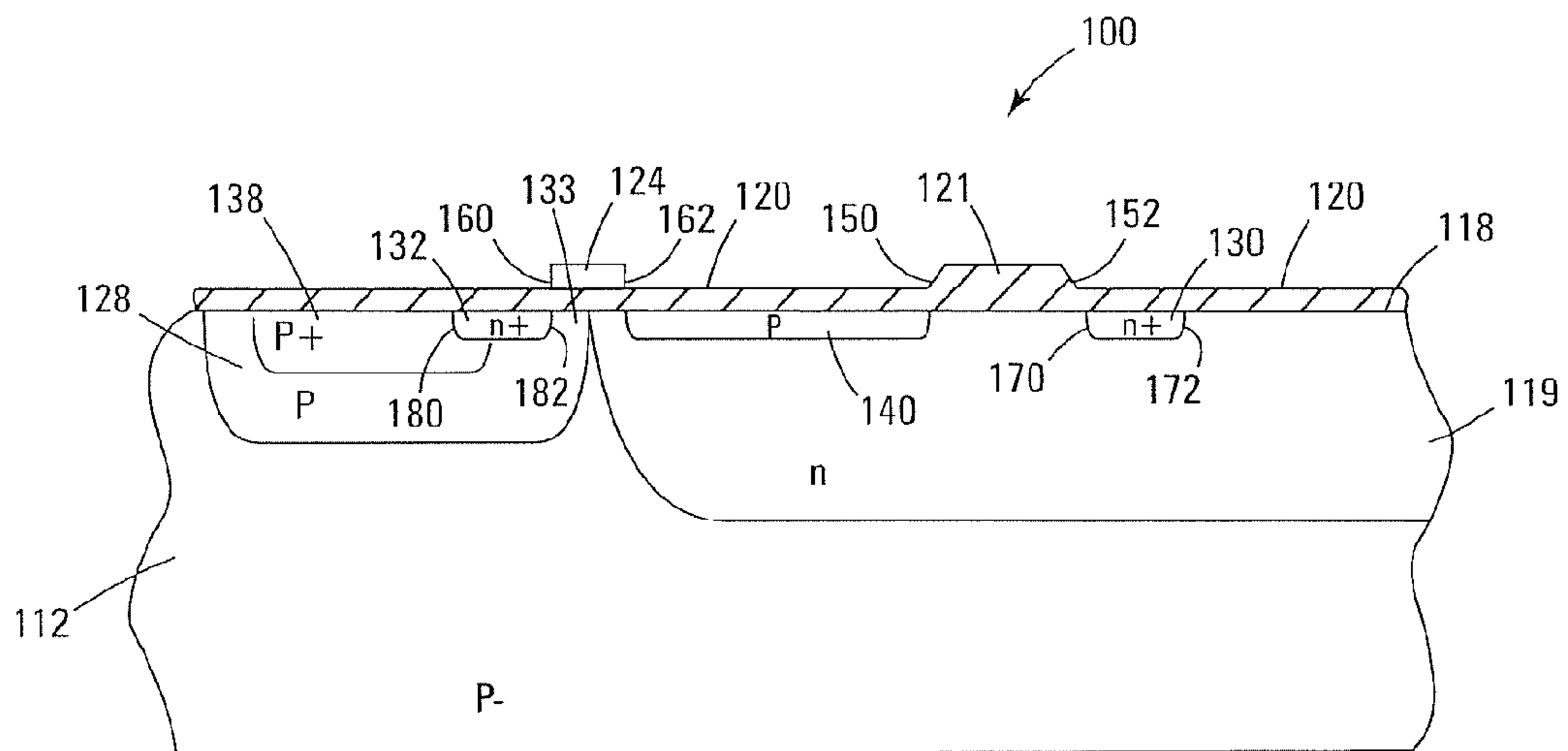

Fig. 9

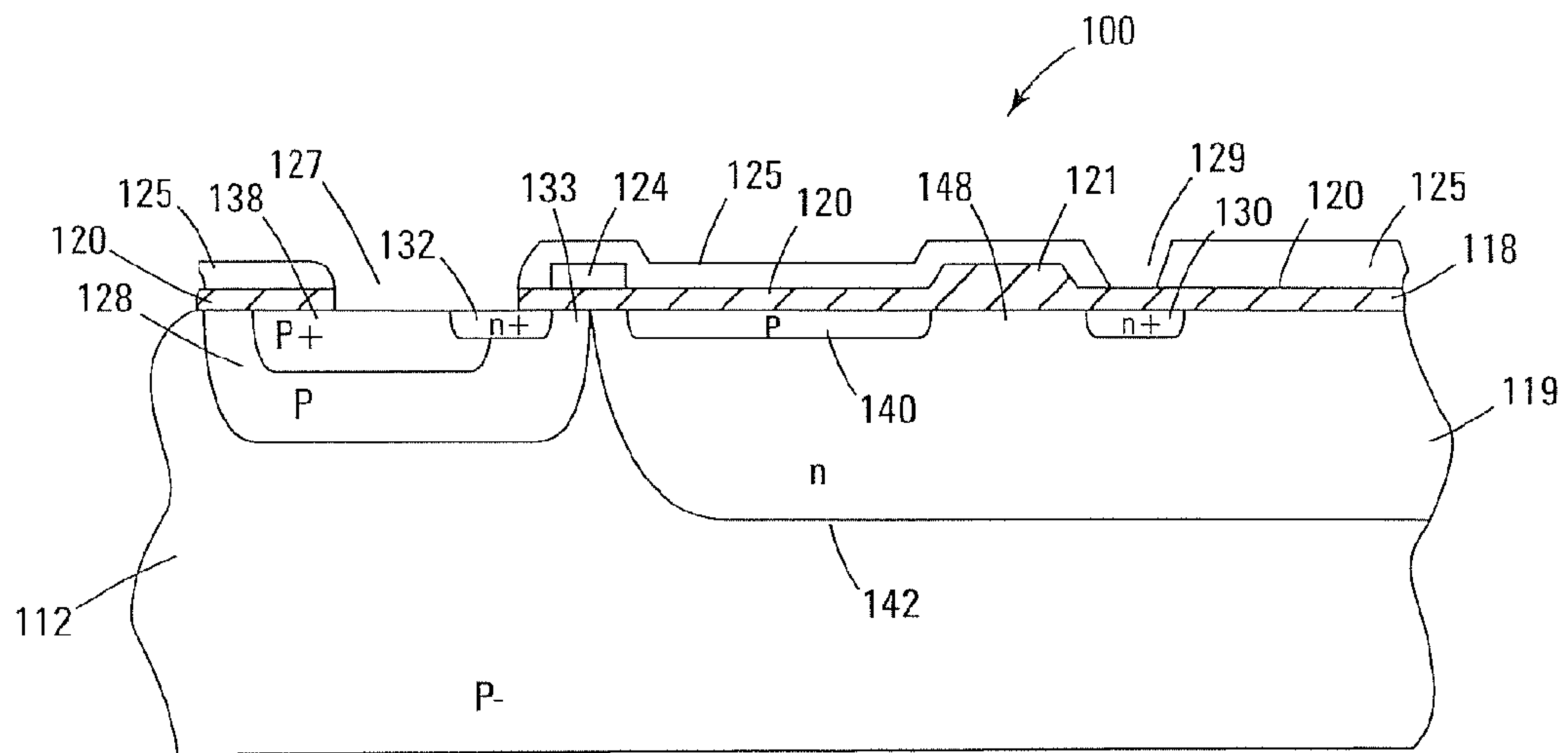

Fig. 10

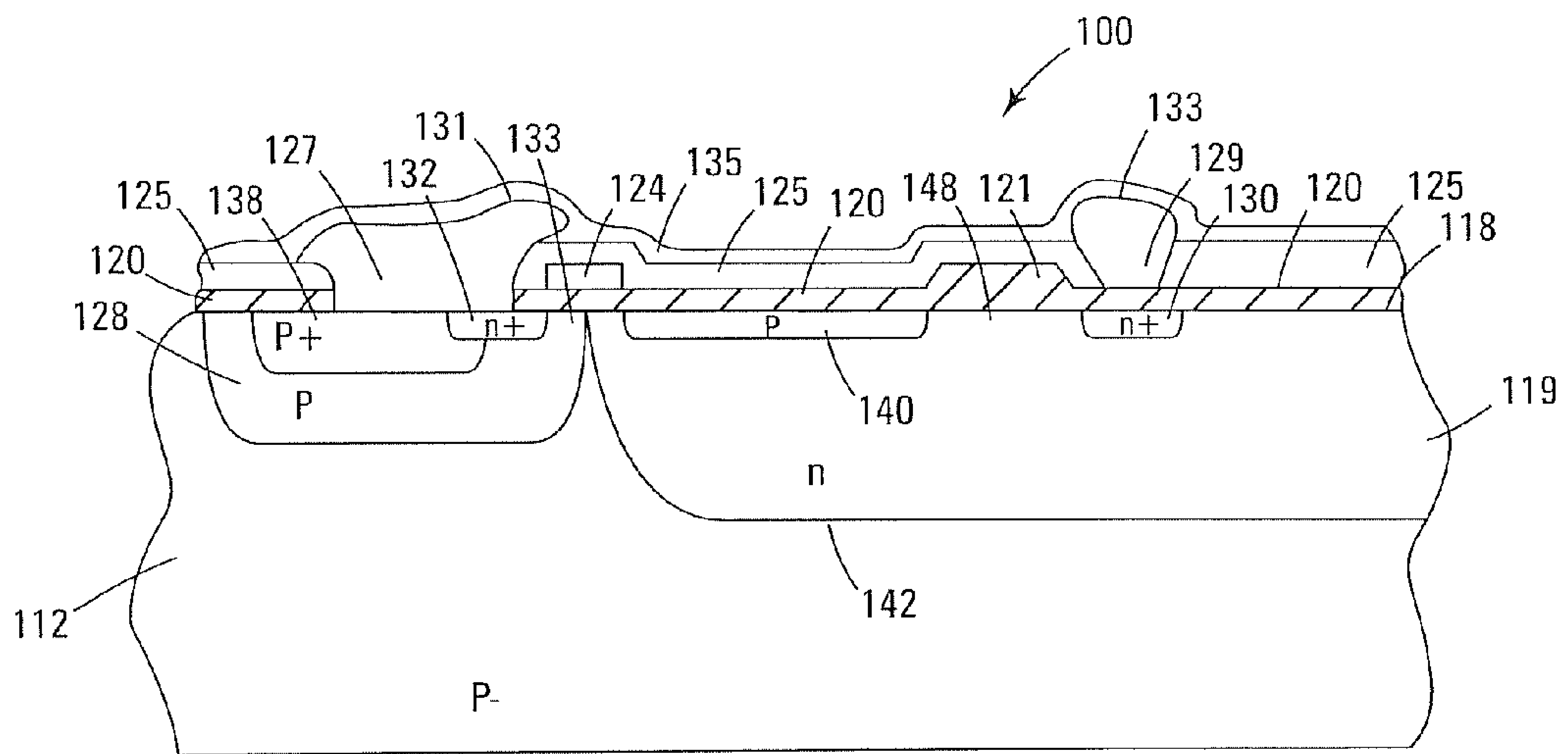

Fig. 10A

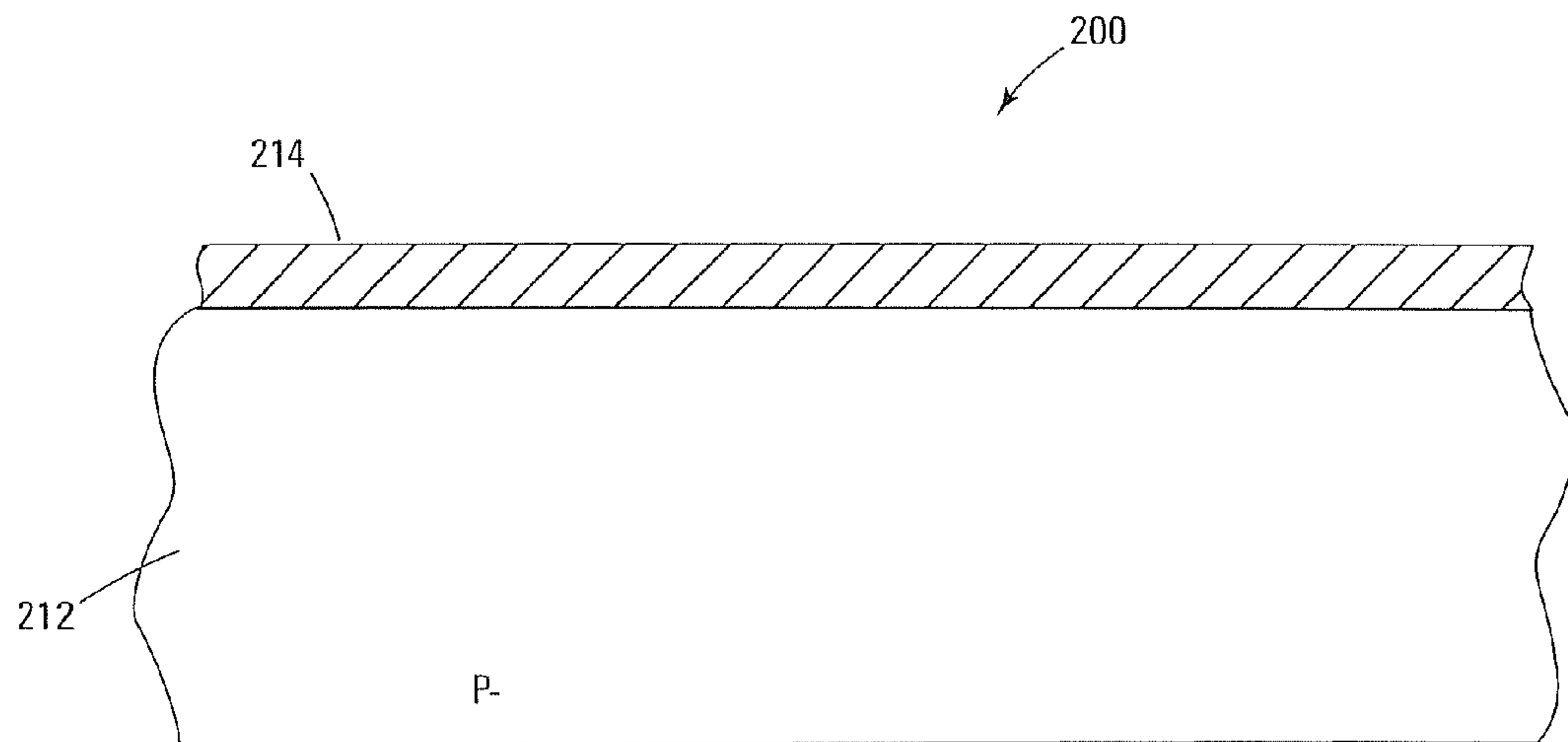

Fig. 11

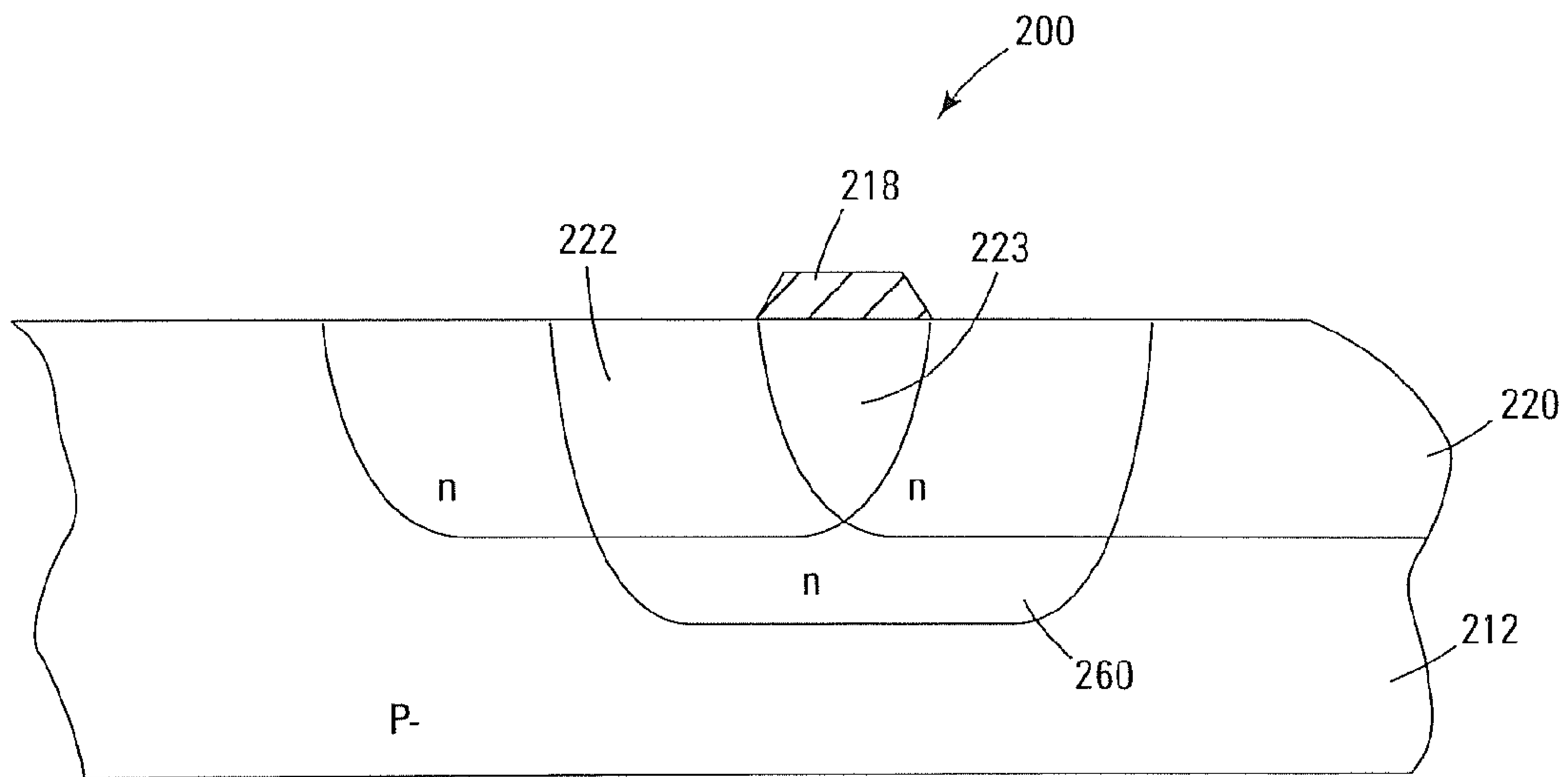

Fig. 12

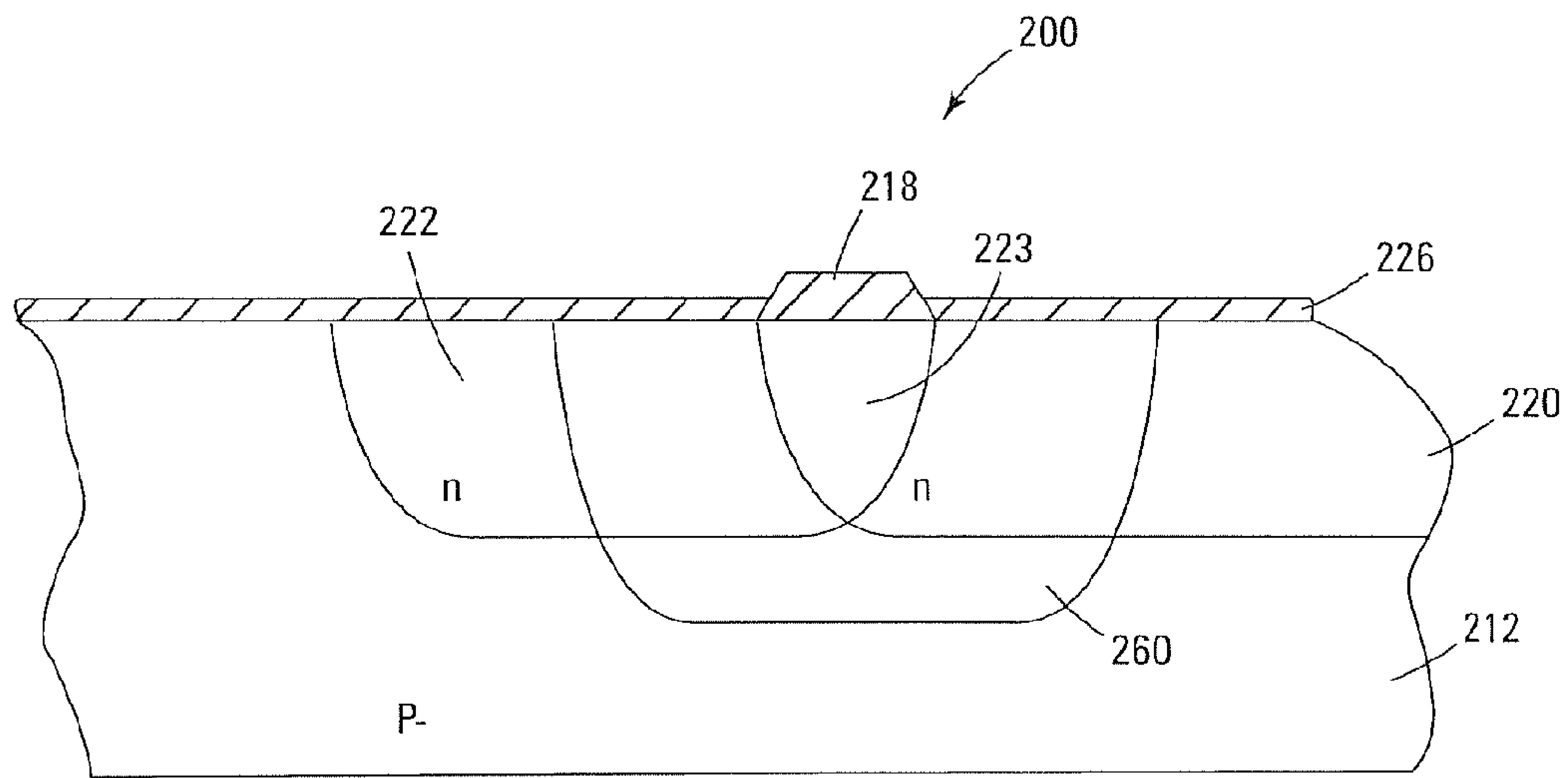

Fig. 13

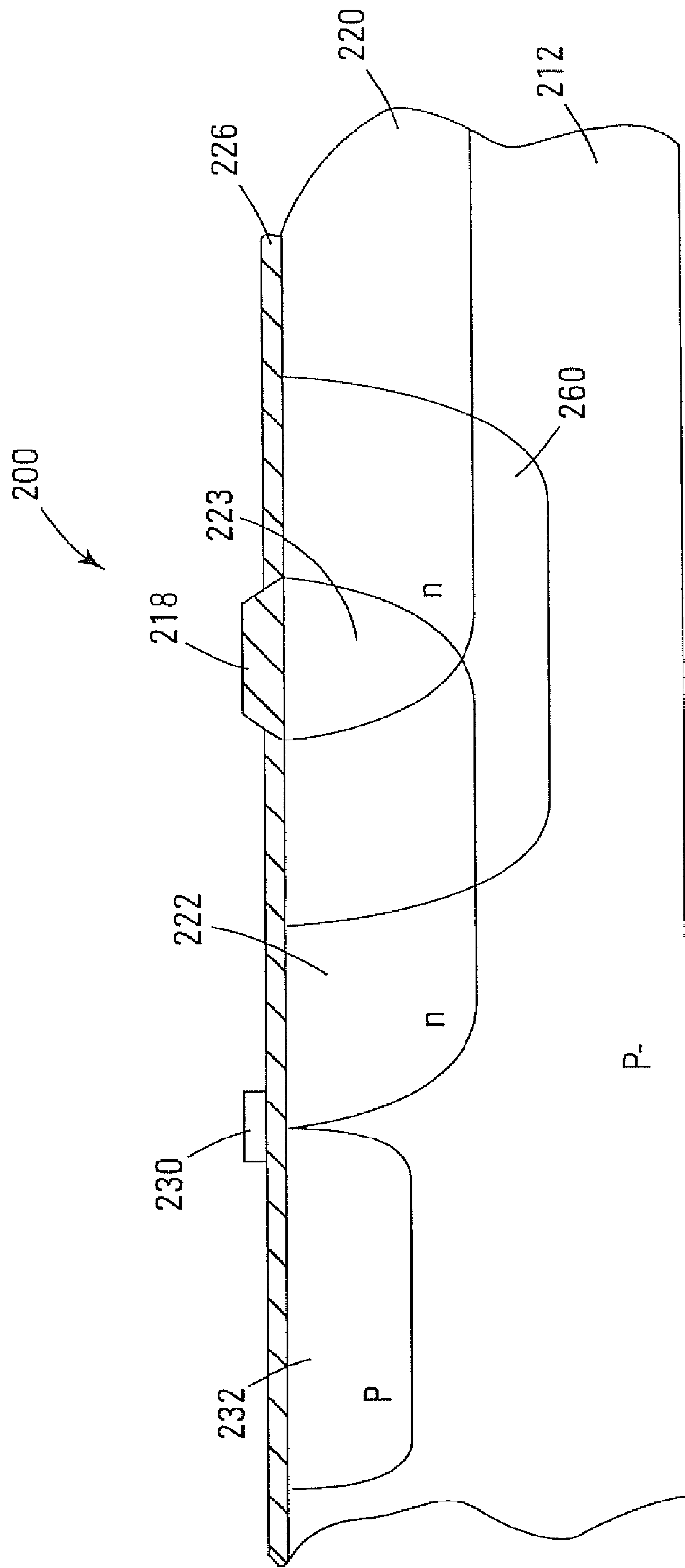

Fig. 14

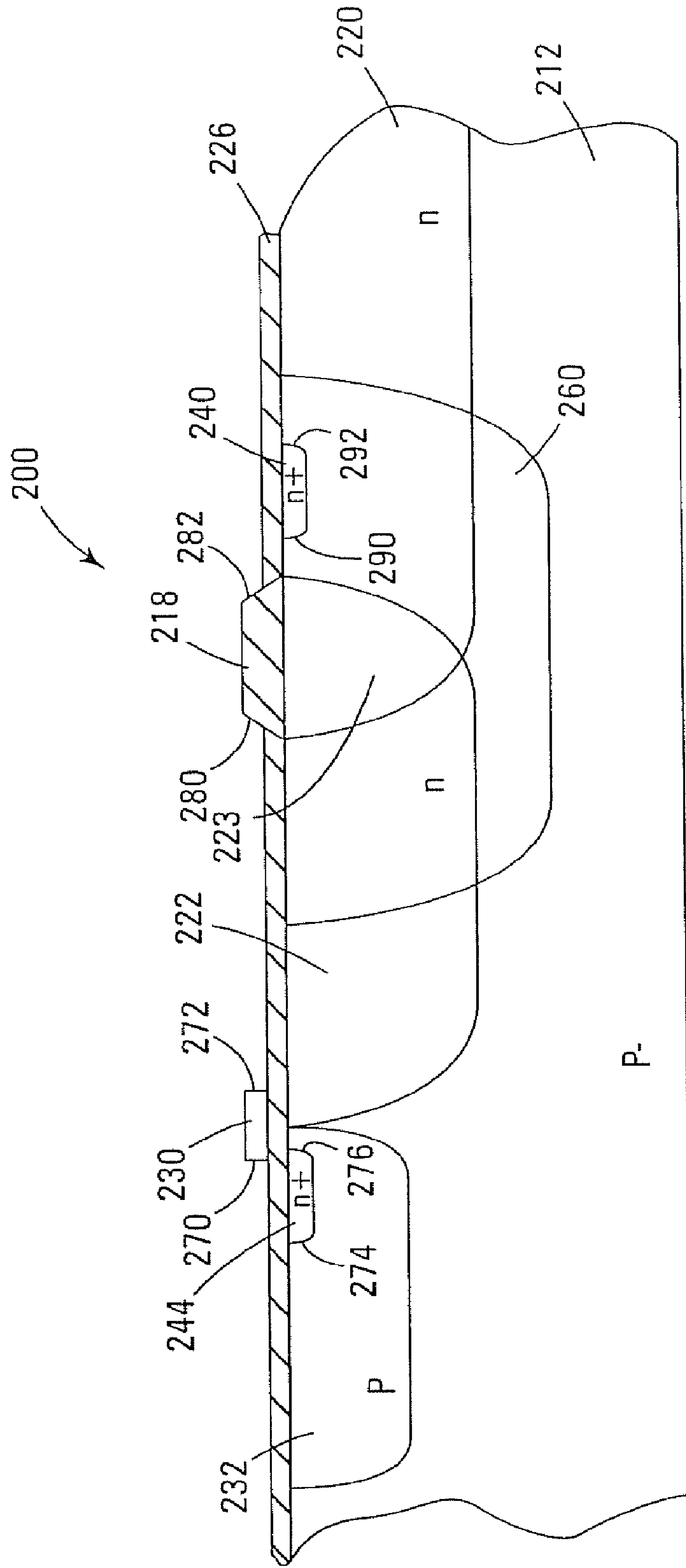

Fig. 15

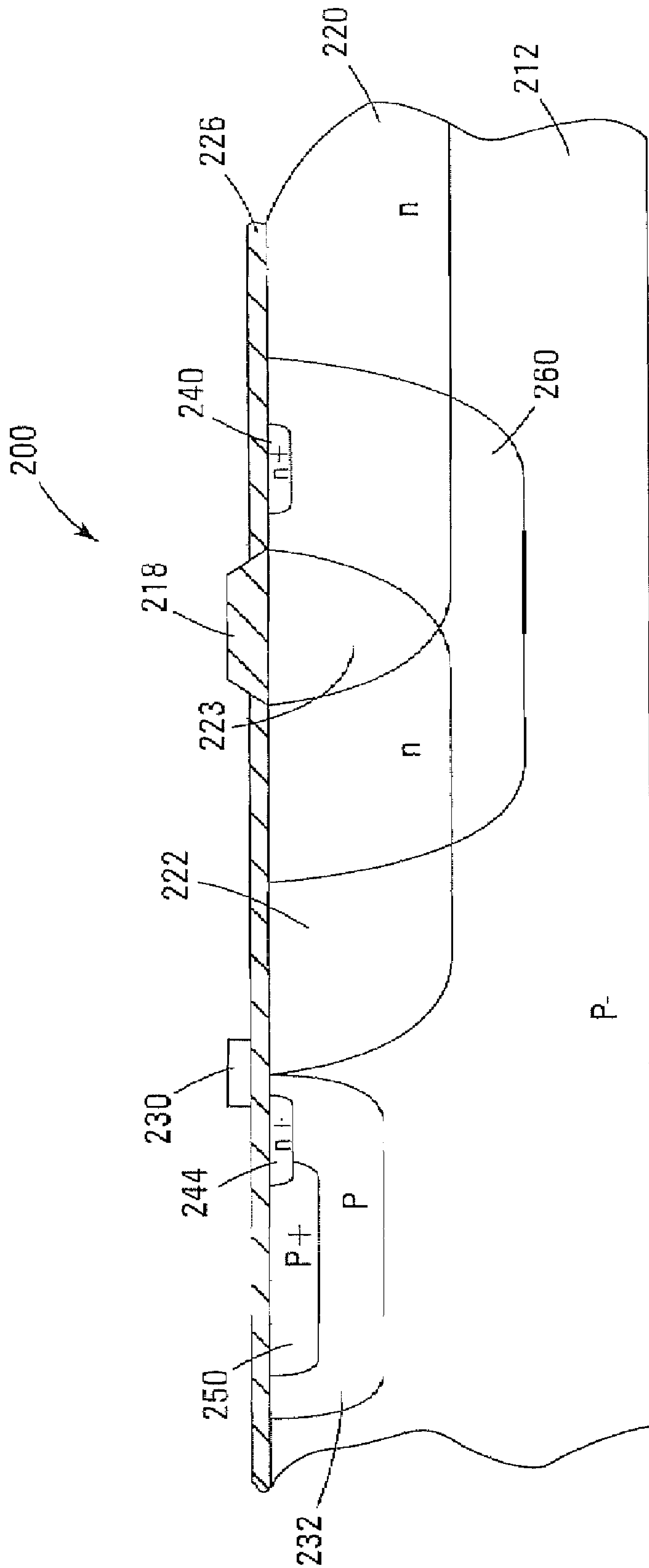

Fig. 16

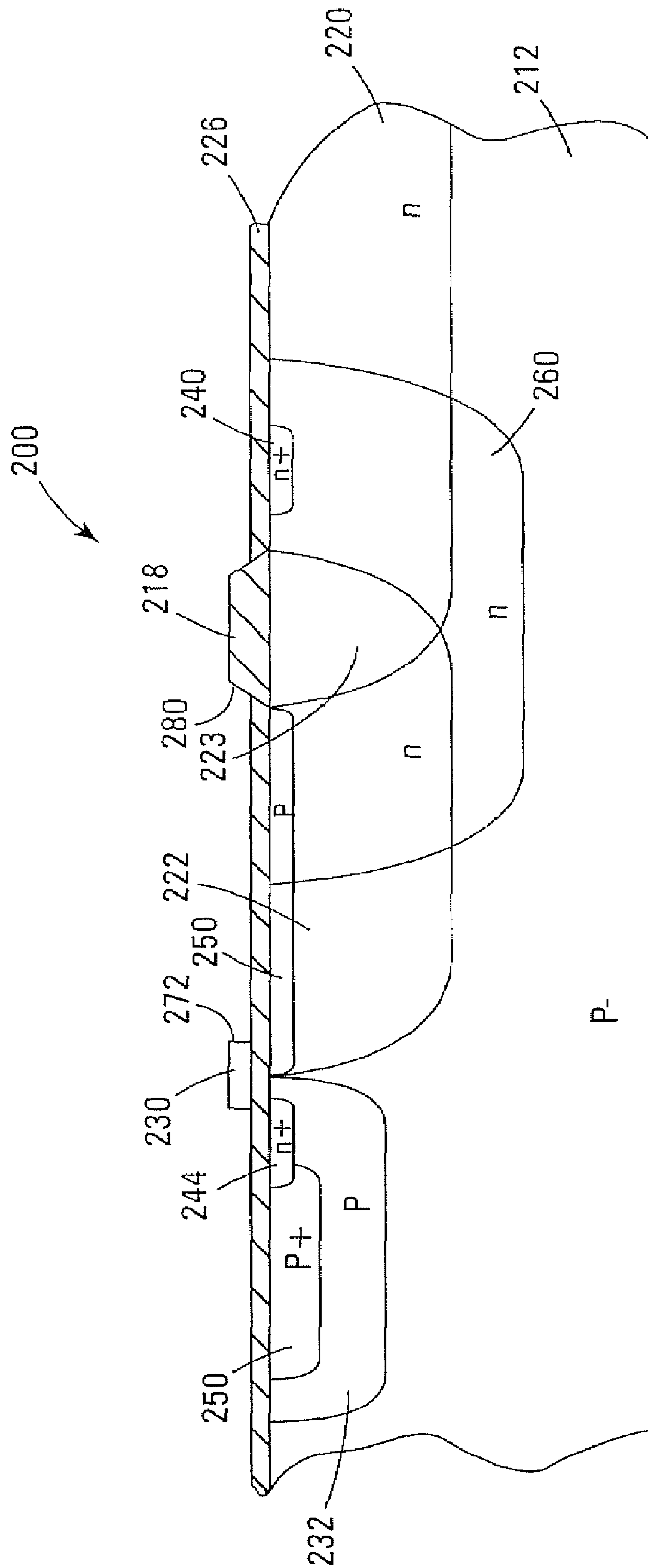

Fig. 17

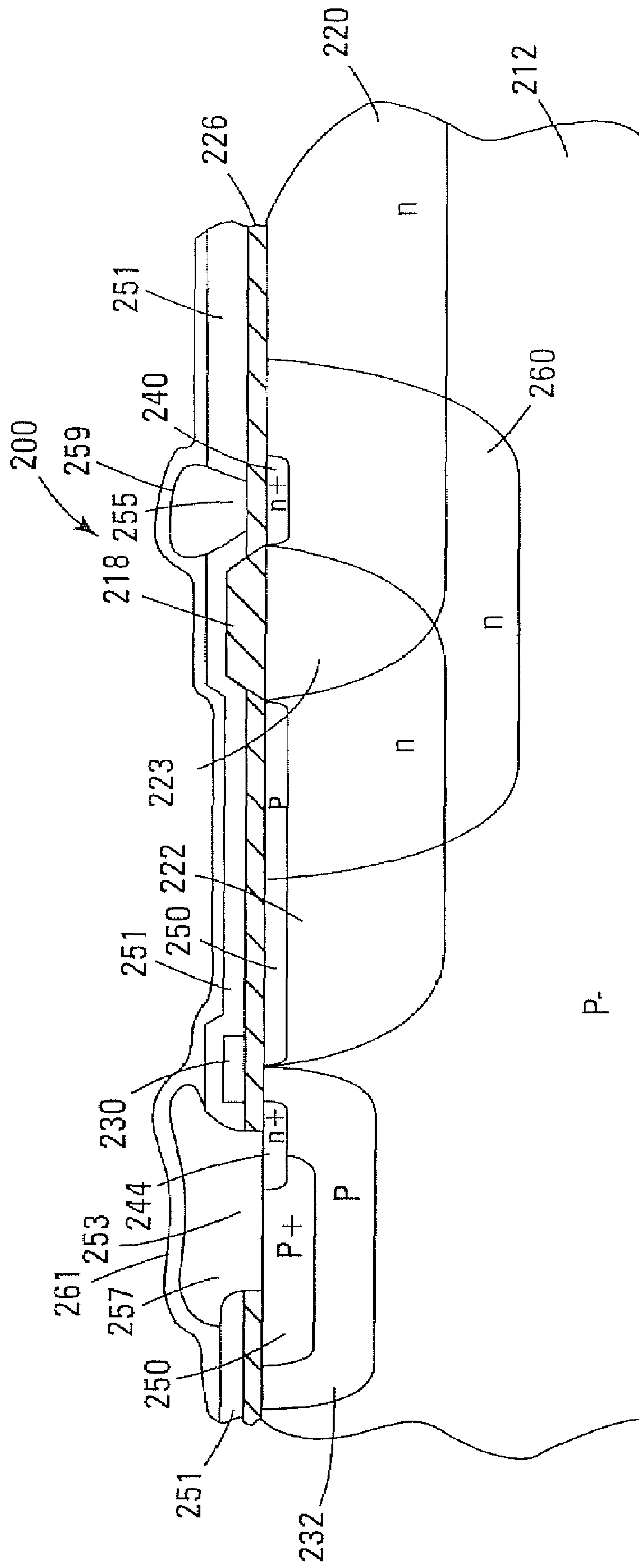

Fig. 18

200 227 212 226 250A 251 225 220 260 219 261 240 255 259 218 223 222 250 230 244 253 261 257 250 251 232 n P n+ n+ P+ P P-

Fig. 18A

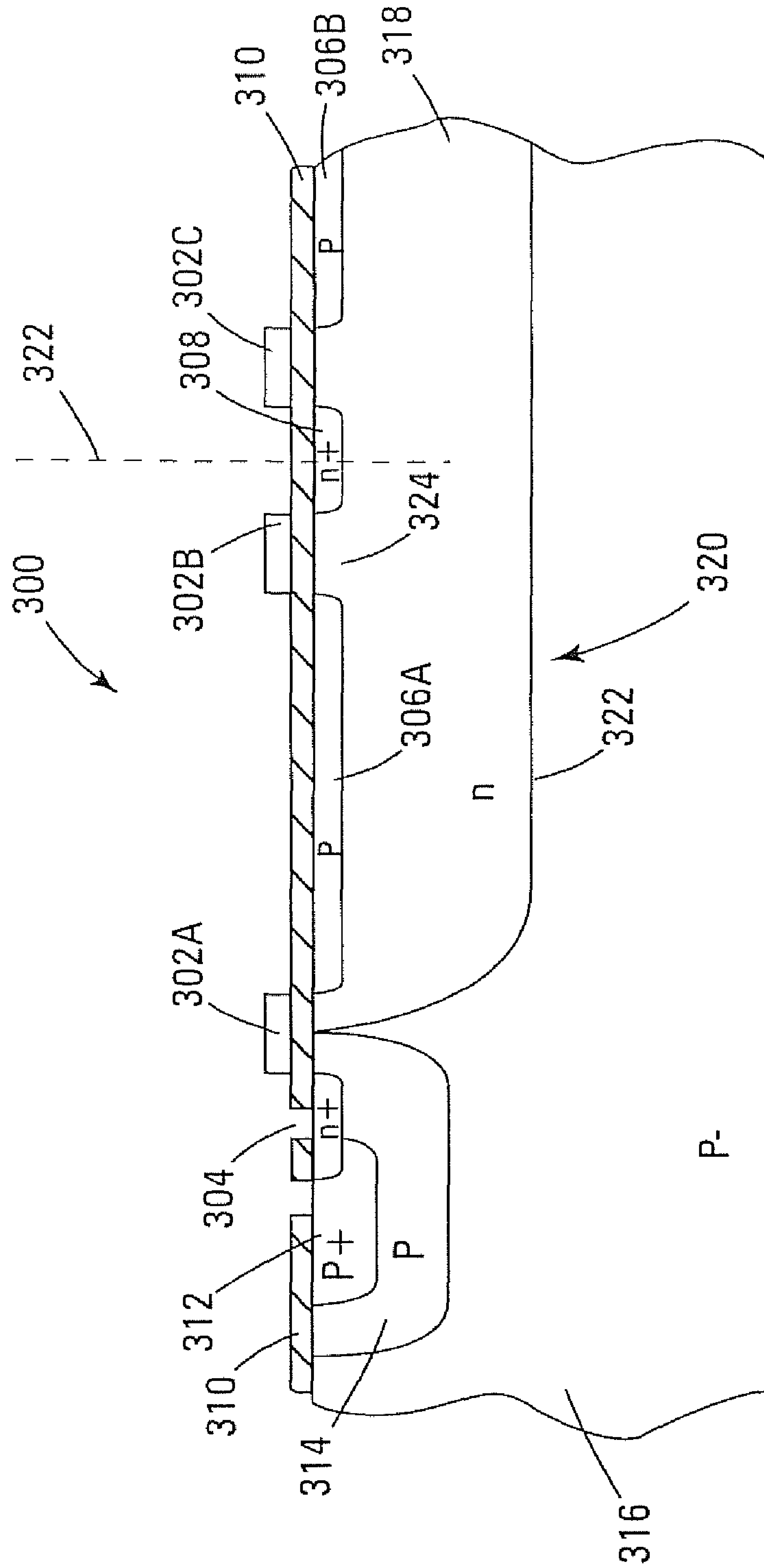

Fig. 19

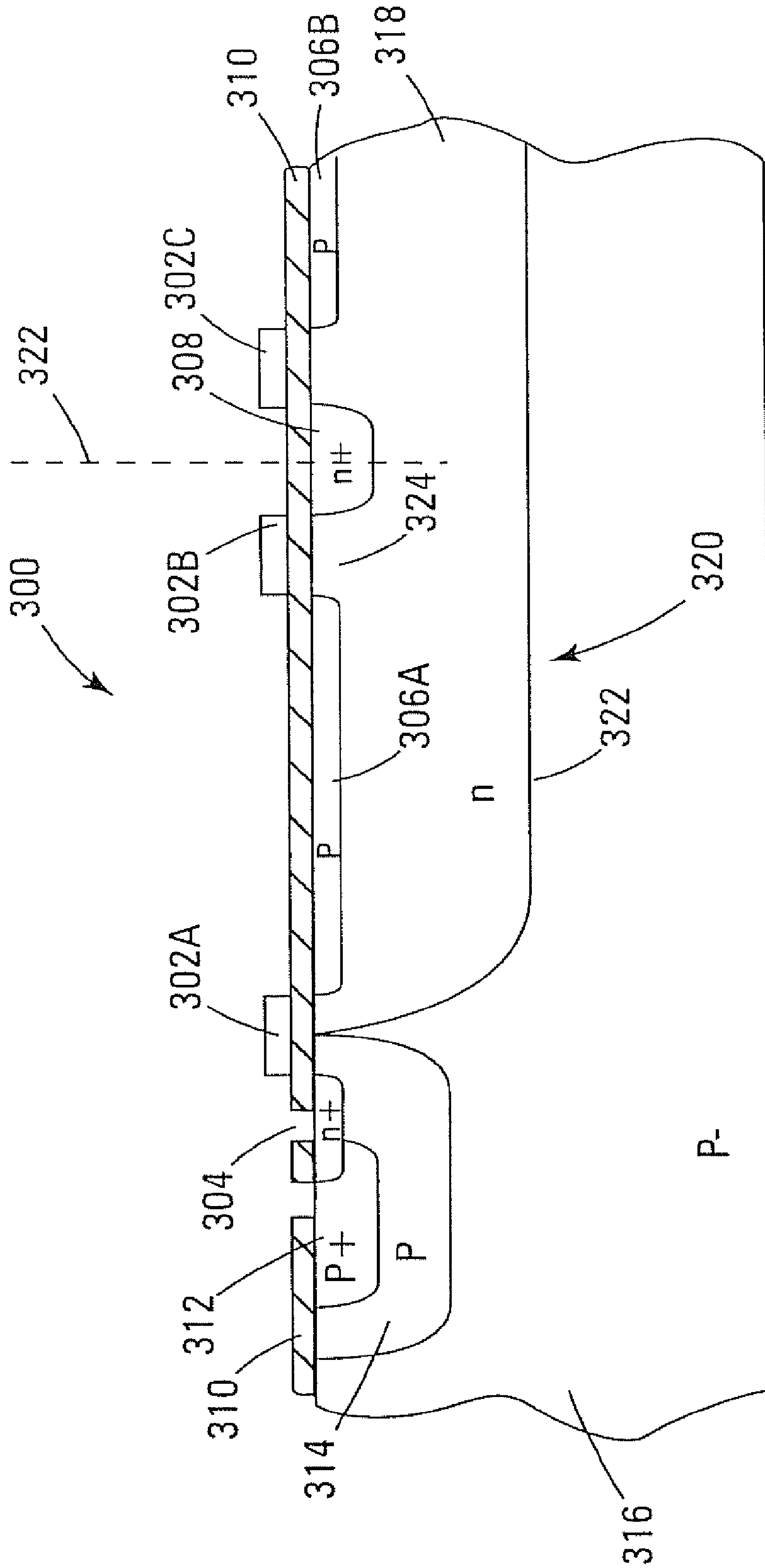

Fig. 19A

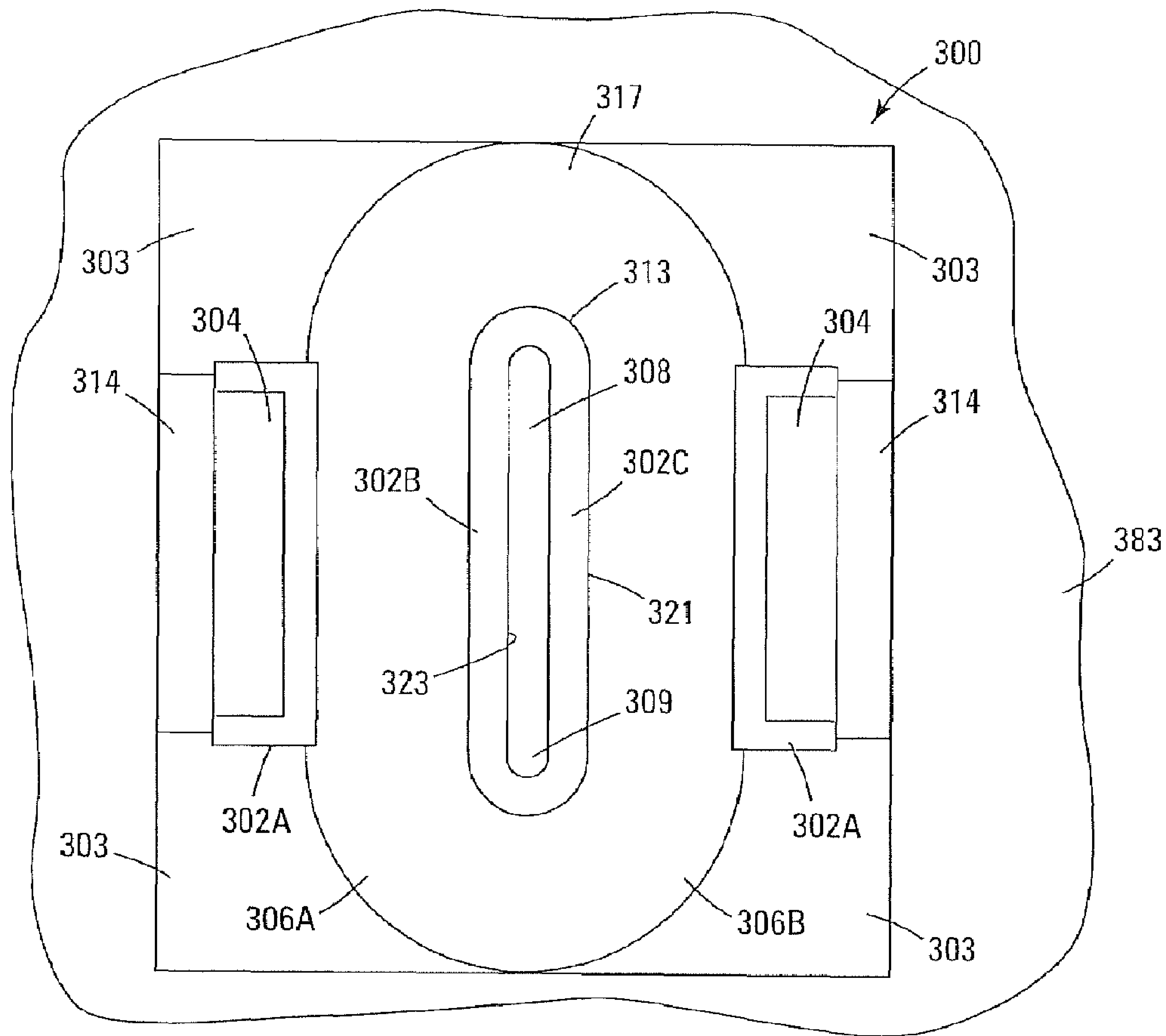

Fig. 19B

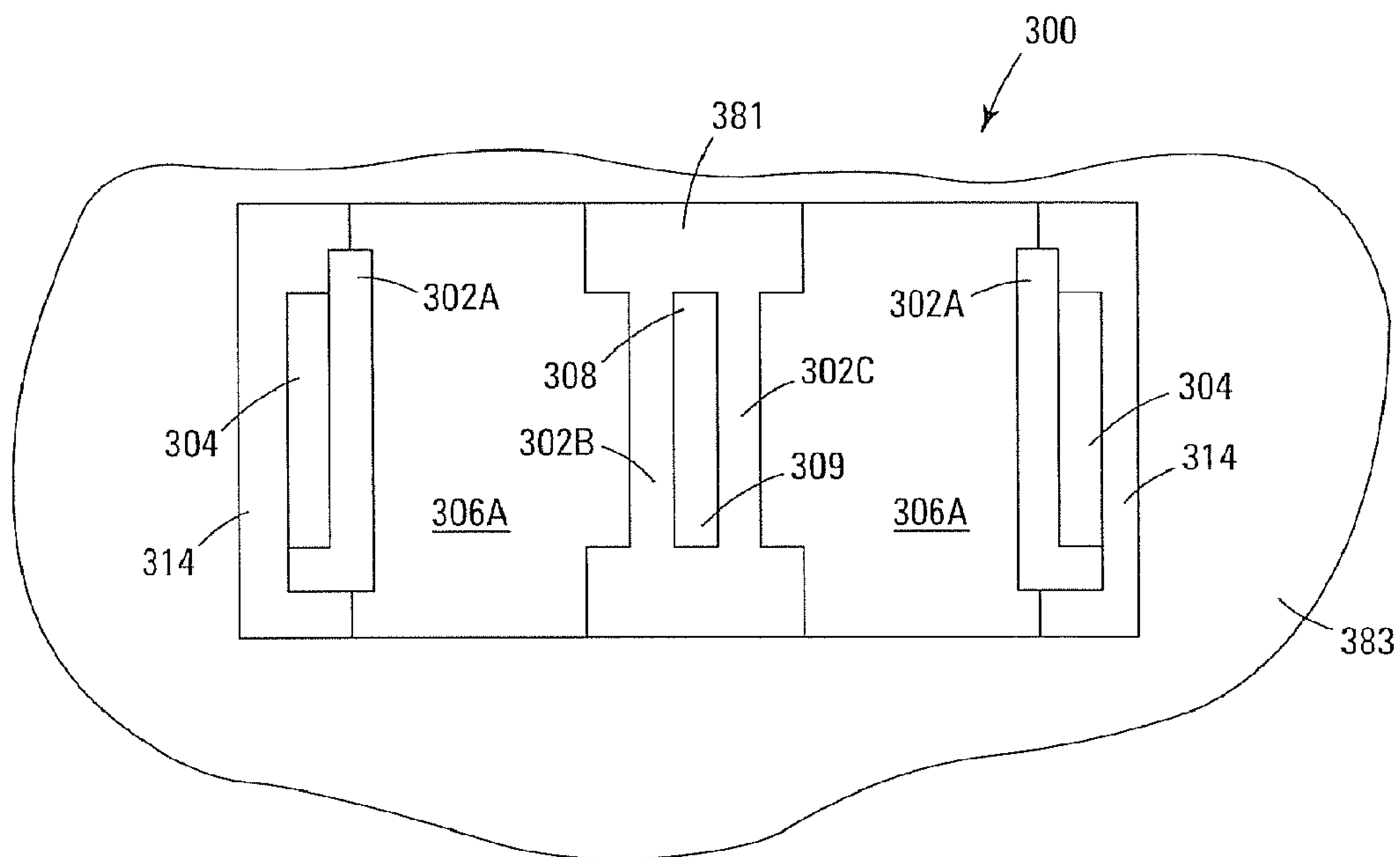

Fig. 19C

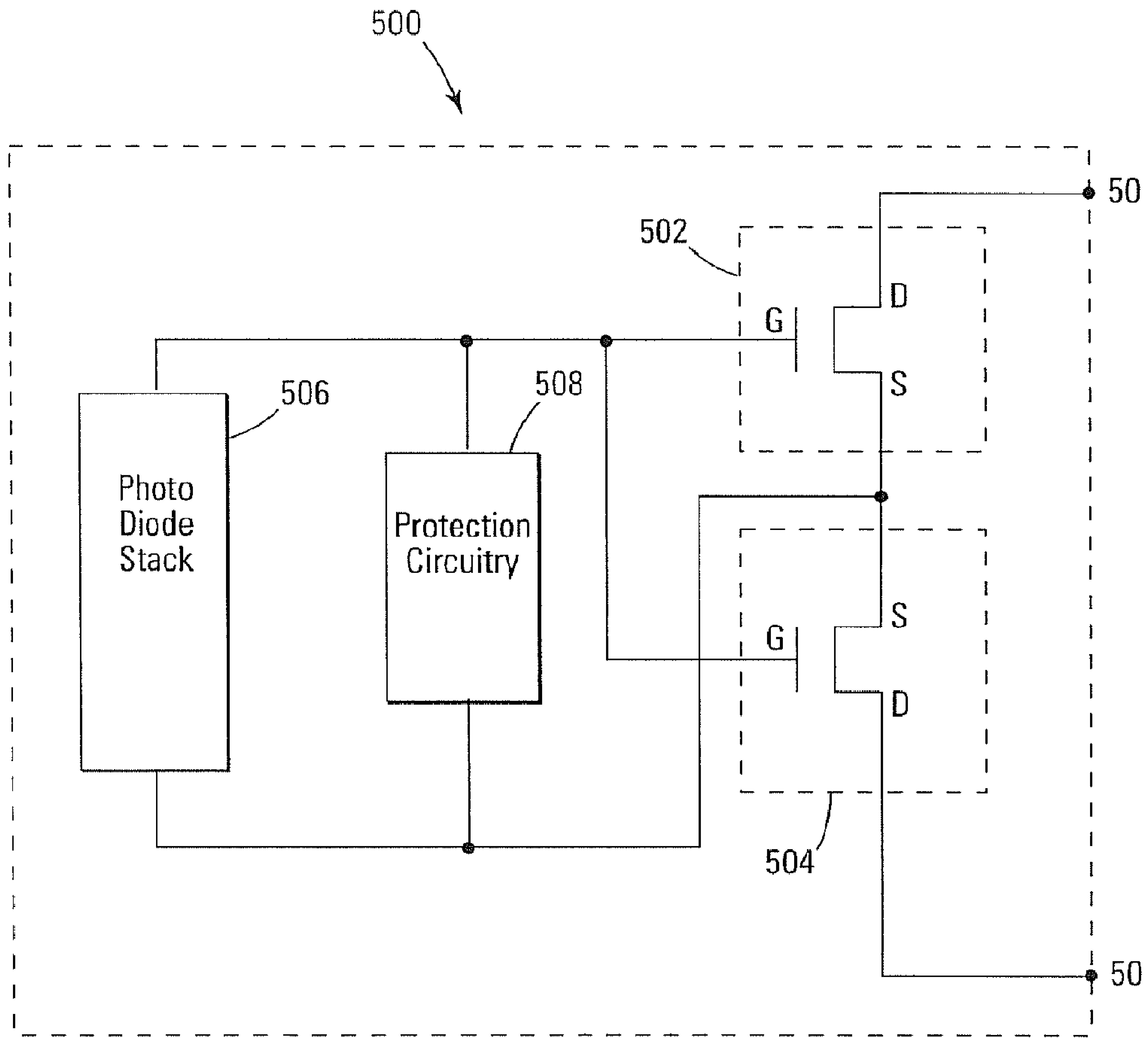

Fig. 20

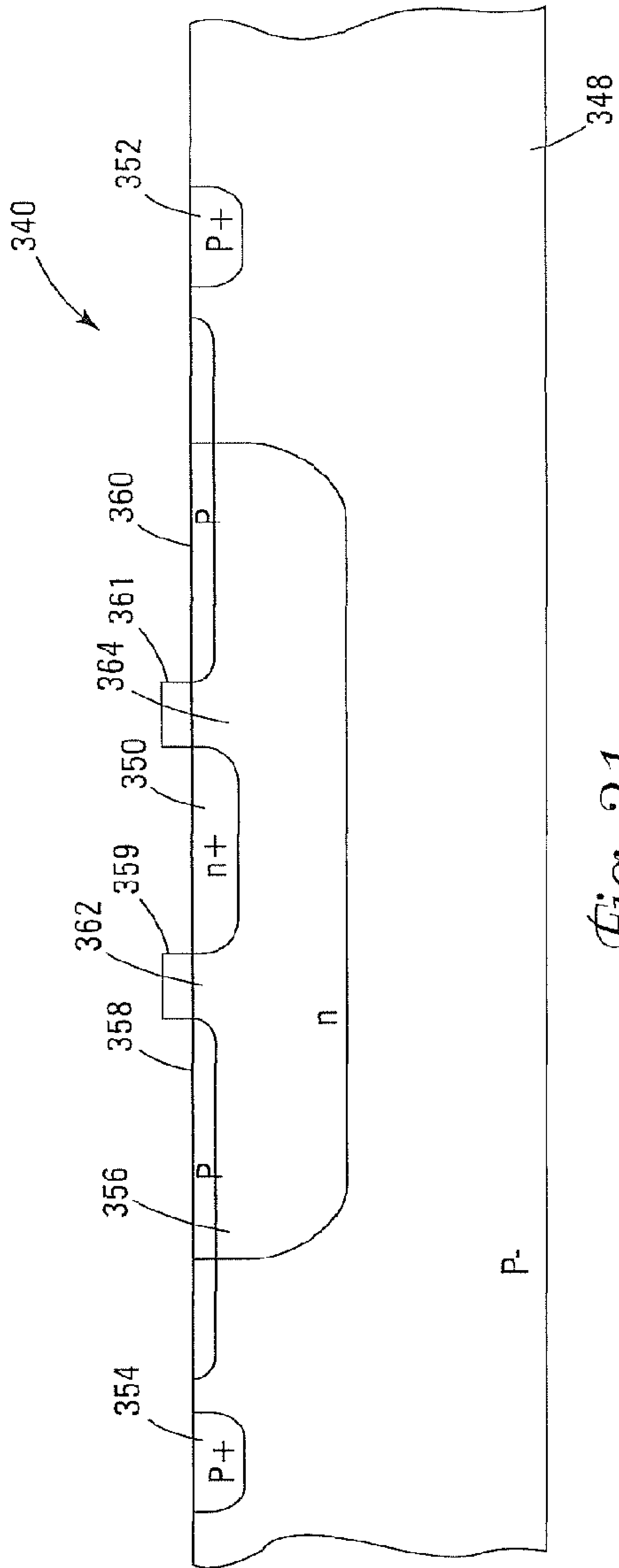

Fig. 21

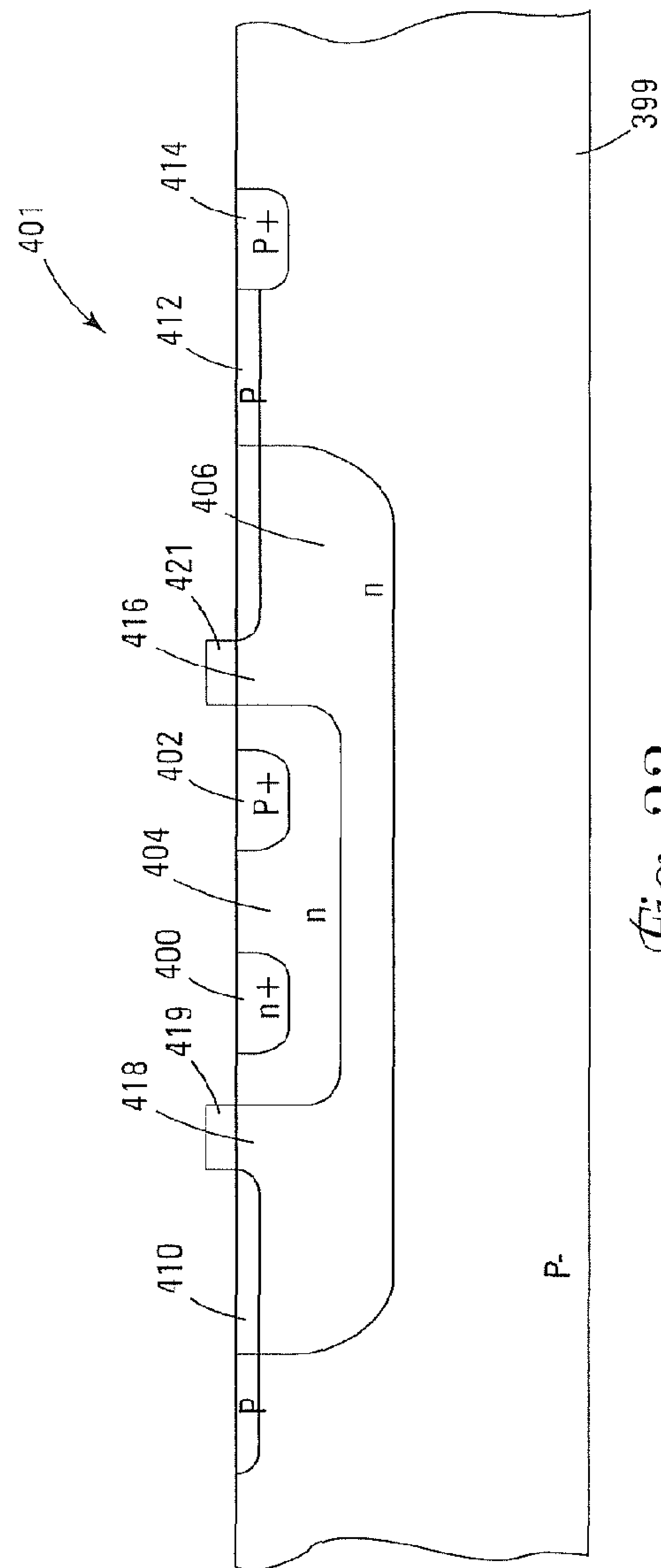

Fig. 22

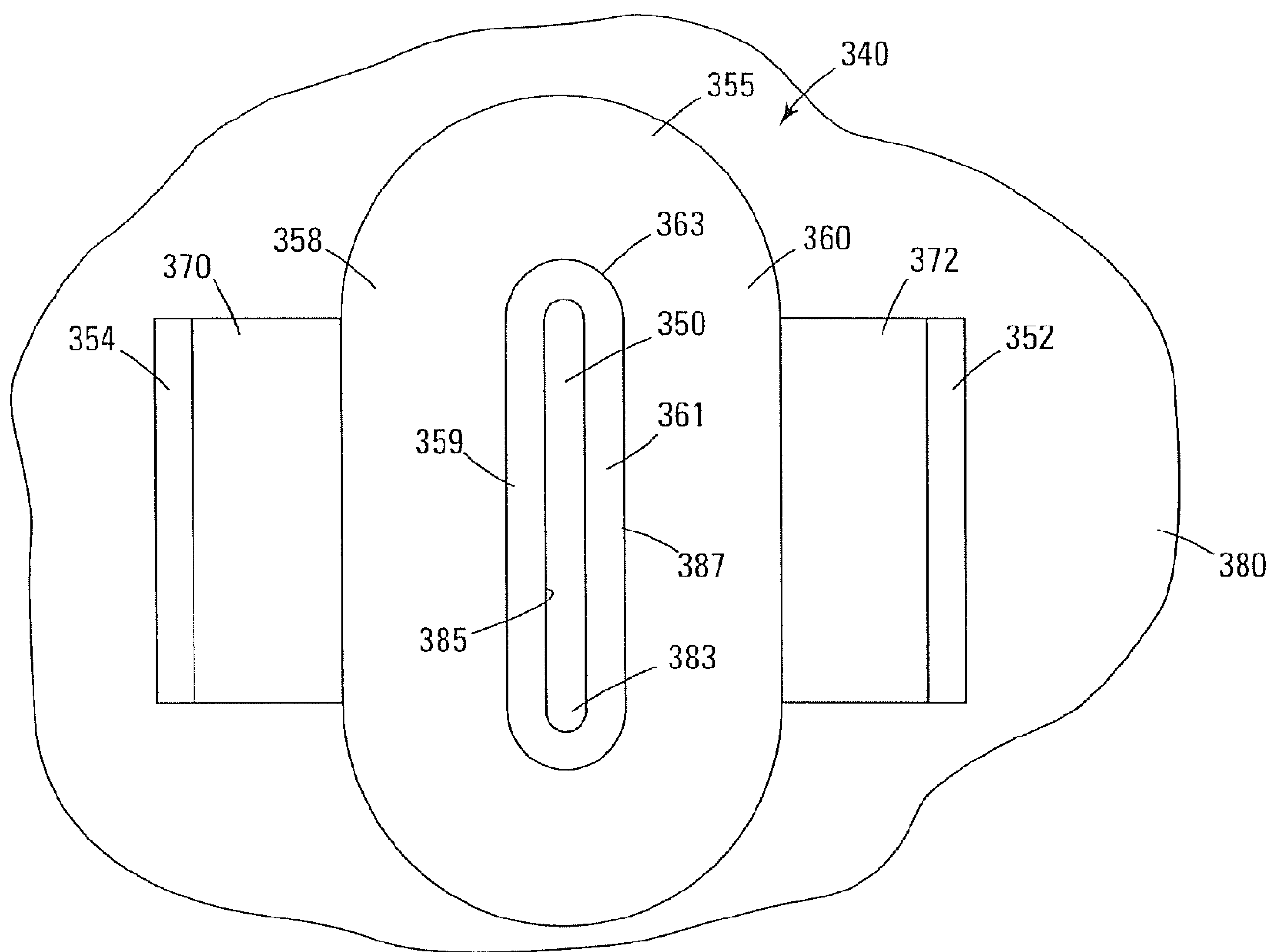

Fig. 21A

METHOD OF MANUFACTURING A MOSFET STRUCTURE

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

CROSS REFERENCE TO RELATED APPLICATION

Notice: More than one reissue application has been filed for the reissue of U.S. Pat. No. 7,687,336. These reissue applications include application Ser. No. 13/235,000, filed on Sep. 16, 2011, and application Ser. No. 13/590,856, filed on Aug. 21, 2012, which is a continuation of application Ser. No. 13/235,000.

This is a Divisional Application of U.S. patent application Ser. No. 11/234,344, filed on Sep. 29, 2005, which is a divisional of application of U.S. Pat. No. 6,974,753, filed Sep. 24, 2004, which is a divisional application of U.S. Pat. No. 6,822, 292, filed Nov. 21, 2001. This divisional application is also related to U.S. Pat. No. 7,161,223, filed Sep. 24, 2004. All of the above applications and patents are incorporated in there entirety by reference.

BACKGROUND

Integrated circuits incorporating high voltage lateral elements include both metal-oxide-semiconductor field-effect transistors (MOSFETs) devices and bipolar junction transistors. A common use of a power MOSFET in an integrated circuit is as an electronic switch. One known high-voltage MOSFET structure for an integrated circuit includes a drain contact connected to the drain end of a channel by a lateral drain extension, which has the same conductively type as the drain contact. High voltage breakdown is achieved by designing the drain extension with an integrated doping (dopant ions per cm^2) such that the drain extension totally depletes at high drain voltages, before the point where avalanche breakdown occurs at a pn junction between the drain extension and the MOSFET body.

Along with size of the structure, there are two other key characteristics of a MOSFET when used in an integrated circuit as an electronic switch. The first is its breakdown voltage and the second is its ON resistance. The breakdown voltage is a measure of the MOSFET's ability to withstand a reversed bias voltage when it is in an OFF or open condition. The ON resistance is a measure of the resistance when the MOSFET is in an ON or closed condition. Improving the operation of the MOSFET switch in an integrated circuit suggests a breakdown voltage as high as possible and an ON resistance as low as possible. A perfect switching device has an infinite breakdown voltage and zero ON resistance. Accordingly, it is desired in the art to reduced the ON resistance. One way of reducing the ON resistance of a lateral MOSFET device is to accurately align various regions of the MOSFET to achieve predefined space between the regions. Unfortunately this is difficult to do with existing techniques because mask edges used to form the various regions introduce an uncertainty factor called an alignment tolerance that contributes to the space between the regions.

For the reasons stated above and for other reasons stated below which will become apparent to those skilled in the art there is a need for a method of accurately controlling the distance between various regions in integrated circuits.

SUMMARY

The above mentioned problems with integrated circuits with high voltage MOSFETs and other problems are addressed by the present invention and will be understood by reading and studying the following specification. The following example summary is given by way of example not by way of limitation.

In one embodiment, a method of forming a high voltage MOSFET for an integrated circuit is provided. The method comprises forming a relatively thin layer of dielectric on a surface of a substrate. Depositing a gate material layer on the relatively thin layer of dielectric. Removing portions of the gate material layer to form a first and second gate material regions of predetermined lateral lengths. Introducing a first conductivity type dopant in the substrate to form a top gate using first edges of the first and second gate material regions as masks, wherein the top gate is formed adjacent the surface of the substrate and laterally between the first and second gate material regions. Introducing a second conductivity dopant of high dopant density in the substrate to form a drain region adjacent the surface of the substrate using a second edge of the second gate material region as a mask to form a first edge of the drain region, wherein the second gate material region is positioned laterally between the drain region and the top gate and wherein the spaced distance between the top gate and the drain region is determined by the lateral length of the second gate material region.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention can be more easily understood and the further advantages and uses thereof more readily apparent, when considered in view of the description of the preferred embodiments and the following figures in which:

FIGS. **1** and **2** are cross-sectional views of prior art MOSFET devices;

FIG. **3** is a cross-sectional view of a MOSFET device of the prior art to which the teachings of the present application can be applied;

FIGS. **4** through **10**A illustrate, in a cross-section view, one embodiment of the present invention during sequential fabrication steps;

FIGS. **11** through **18**A illustrate, in a cross-section view, embodiments of the present invention during sequential fabrication steps;

FIG. **19** is a cross-section view illustrating the use of gate material as a mask of one embodiment of the present invention;

FIG. **19**A is a cross-sectional view illustrating drain and contact regions formed deeper than the top gate of one embodiment of the present invention;

FIG. **19**B is a top view of one embodiment of a MOSFET of the present invention;

FIG. **19**C is a top view of another embodiment of a MOSFET of the present invention;

FIG. **20** is a block diagram of a solid state relay incorporating MOSFETs of the present invention;

FIG. **21** is a cross-sectional view of a pn junction diode for an integrated circuit of one embodiment of the present invention;

FIG. **21**A is a top view of one embodiment of a pn junction diode for an integrated circuit of the present invention; and

FIG. **22** is a cross-sectional view of a bipolar transistor for an integrated circuit of one embodiment of the present invention.

In accordance with common practice, the various described features are not drawn to scale but are drawn to emphasize specific features relevant to the present invention. Reference characters denote like elements throughout the Figures and text.

DETAILED DESCRIPTION

In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings, which form a part hereof, and in which is shown by way of illustration specific preferred embodiments in which the inventions may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that logical, mechanical and electrical changes may be made without departing from the spirit and scope of the present invention. The following detailed description is therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the claims and equivalents thereof.

Embodiments of the present invention relate to integrated circuits having relatively accurate aligned regions that are spaced a predetermined distance apart from each other. Moreover, some embodiments of the present invention relate to integrated circuits having a MOSFET structure with a drain region spaced apart from a top gate a predetermined distance. In the following description, the term substrate is used to refer generally to any structure on which integrated circuits are formed, and also to such structures during various stages of integrated circuit fabrication. This term includes doped and undoped semiconductors, epitaxial layers of a semiconductor on a supporting semiconductor or insulating material, combinations of such layers, as well as other such structures that are known in the art. Terms of relative position as used in this application are defined based on a plane parallel to the conventional plane or working surface of a wafer or substrate, regardless of the orientation of the wafer or substrate. The term "horizontal" or "lateral" as used in this application is defined as a plane parallel to the conventional plane or working surface of a wafer or substrate, regardless of the orientation of the wafer or substrate. The term "vertical" refers to a direction perpendicular to the horizontal. Terms, such as "on", "side" (as in "sidewall"), "right", "left", "higher", "lower", "over," "top" and "under" are defined with respect to the conventional plane or working surface being on the top surface of the wafer or substrate, regardless of the orientation of the wafer or substrate. Before a detailed discussion of the embodiments of the present invention are described, further background is first provided to aid in the understanding of the embodiments of the present invention.

Referring to FIG. **1**, a cross-sectional view of a known high voltage lateral MOSFET device **8** is illustrated. As illustrated, the MOSFET device **8** includes a gate **10**, a source **12** with P+ doping concentration and a drain **14**. The drain **14** includes a P+ region **14**a formed in a P− shield region **14**b. The "+" indicates a high dopant density and the "−" indicates a low dopant density. The MOSFET device **8** further includes a silicon dioxide (SiO_2) layer **13** overlying the various active regions as shown. A body **11** of the device **8** is doped with a N-type dopant. A drift region **17** or drain extension **17** is doped with a P type dopant and extends along the top surface of the body **11**. The drain extension **17** further has one edge adjacent to the P− shield region **14**b. The drift region **17** forms a portion of the conducting path between the source **12** and the drain **14**. A body contact **16** is also illustrated. In operation, the drain **14** is connected to a negative supply voltage, and the source **12** and body **11** are connected together and further connected to a positive supply voltage. Typically, the drain **14** is connected to ground and a positive supply voltage is supplied to the shorted source **12**/body **11**. More generally, the drain **14** is at a lower potential than the shorted source **12**/body **11**.

The drift region **17** serves as a JFET (function field-effect transistor) channel. A region **11**a of the body **11**, underlying the drift region **17** provides a JFET gate function with respect to the channel of the drift region **17**. The drift region **17** is designed to totally deplete (i.e., a pinch-off condition is created) at a voltage lower than the reverse bias voltage at which avalanche breakdown occurs in the pn junction between the drift region **17** and the body **11**. The electric field of the fully depleted drift region **17** is determined by the applied drain voltage. The electric field across the pn junction depends on the relative concentrations of the two doped regions and is maximum at the metallurgical junction between the regions. Thus most of the reverse bias voltage is dropped across the depleted region. The length and doping concentration of the drift region **17** determine the maximum electric field that the drift region **17** can support. The source **12** and the gate **10** are safely shielded from the high drain voltage by the pinched off depleted drift region **17**.

The resistance of the drift region **17** is in series with the resistance of the channel **11**b, consequently, the total ON resistance of the device **8** is simply the sum of these two individual resistances. The drift region **17**, which must be quite long to sustain the high reverse bias drain-source voltage, often contributes the larger of the two resistance terms, especially in high-voltage devices (for example, a drain-source voltage greater than 100 V). Thus, it is desirable to reduce the resistance of the drift region **17** so that MOSFET devices can be fabricated with lower channel ON resistance.

It is known that the drain extension resistance is inversely proportional to the drain extension integrated doping. Thus, the ON resistance can be reduced by increasing the integrated doping level. A structure and method that allows the extension integrated doping to be approximately doubled without degrading the voltage characteristics, comprises the addition of a top gate and second extension of opposite conductivity type to the first extension. The second extension is formed within the first extension. Such a dual lateral drain extension device is illustrated in commonly owned U.S. Pat. Nos. 4,823,173 and 5,264,719, which are both hereby incorporated by reference.

FIG. **2** illustrates such a prior art dual lateral drain extension DMOSFET device **48**. The DMOSFET **48** includes a substrate **49** and an N type drift region **50** disposed therein. The DMOSFET **48** further comprises an N+ drain region **51** and a lateral P type top gate **53**, both formed in the drift region **50**. An N+ source region **56** and a P+ substrate contact **58** are both disposed within a P type body **60**. The DMOSFET device **48** further comprises a field oxide layer **61** and a gate **62** overlying a gate oxide layer **64**. The device channel is identified by a reference character **65** and can be referred to as the MOS channel **65**. The top gate **53** is electrically connected to the substrate **49** in the third dimension outside the plane of FIG. **2**.

The structure of FIG. **2** provides reduced ON resistance relative to the MOSFET device shown in FIG. **1** above. The reduction in ON resistance is accomplished by providing a structure with increased drift region doping (the drift region **50**) without reducing the body-to-drain reverse bias break-

down voltage. This is made possible by inclusion of the top gate **53**, which serves as a JFET top gate. The depletion layer at the boundary between the top gate **53** and the drift region **50** holds some drift region charge when reverse biased, which is in addition to the charge held by the depletion layer between a region **66** of the substrate **49**, and the drift region **50**. Note that the region **66** serves as a JFET bottom gate and is electrically connected to the top gate **53** via the substrate **49**. This additional charge, in the form of fixed ionized impurity atoms, causes the channel resistance reduction. It is possible to provide approximately twice the integrated doping level in the drift region **50** than previously acceptable due to this ability to hold drift region charge. The drift region **50** of the prior art has an exemplary integrated doping of 1×10^{12} phosphorous (or more generally n-type) atoms per square centimeter. Including the top gate **53** with an integrated doping of about 1×10^{12} ions per square centimeter, a doping level of 2×10^{12} n-type atoms per square centimeter is possible in the drift region **50**. Thus, the ON resistance in the FIG. **2** device is half the ON resistance of the prior structures.

To optimize performance of the FIG. **2** structure, the top gate **53** should preferably be designed differently than a conventional JFET gate. That is, the top gate **53** should totally deplete at a body-to-drain voltage less than the reverse bias breakdown voltage of the pn junction **68** formed between the top gate **53** and drain region **51**. The body-to-drain voltage is used as a reference because the top gate **53** is in contact with the body **49** in the third dimension outside the plane of FIG. **2**. Therefore, the voltage at pn junction **68** equals the voltage at a pn junction **70** formed between the drift region **50** and the body **49**. The voltage at which pn junction **68** is designed to breakdown should be greater than the voltage at which the top gate **53** totally depletes. Further, the top gate **53** should totally deplete before the depletion layer between the body **49** and the drift region **50** reaches the depletion layer between the top gate **53** and the drift region **50**. This condition assures that a large voltage differential between the top gate **53** and the drain region **51** is not developed by punch-through action from the body **49**. As is known by those skilled in the art, a conventional JFET gate (compared to the JFET action of the top gate **53**) never totally depletes regardless of operating conditions.

One method of fabricating the MOSFET **48** of FIG. **2** is to form the top gate **53** or both the drain drift region **50** and the top gate **53**, after the MOSFET gate **62** has been formed. Using this technique, the JFET top gate **53** can be self-aligned to the MOSFET gate **62** by using the latter as a mask when the JFET top gate **53** is formed, preferably by ion implantation. Process simulations of the MOSFET **48** of FIG. **2** indicate a high electric field at the junction between the drain contact **51** and the top gate **53**. Thus the reverse bias breakdown is more likely to occur at the junction **68** than at other regions of the drain/body pn junction. The high breakdown voltage characteristic may be recovered by spacing the top gate **53** apart from the drain region **51** as illustrated by a MOSFET **90** in FIG. **3**. Simulations of the embodiment illustrated in FIG. **3**, achieve the desired reverse bias breakdown voltage for MOSFET **90**. Current processes used to form the structure illustrated in FIG. **3** implement separate mask steps that require alignment to define the distance between the top gate **53** and the drain region **51**. However, extra mask steps, especially those requiring an alignment tolerance, are undesirable in the fabrication process as they increase the fabrication cost and protract fabrication time.

In particular, with current production processes, the edge of the drain region **51** is defined by the location of an edge of an opening in a photo resist mask that serves to define where the drain region **51** is formed in the substrate **49**. Similarly, the edge of the top gate **53** is also defined by the location of an opening in another photo resist mask that defines the location of the formation of the top gate **53**. These two masks are aligned to a previous formed reference pattern. Thus there are two alignment uncertainties between the edges of the photo resist masks that define the edge of the drain region **51** and the edge of the top gate region **53**. Using projection aligners to perform the alignment of each of the photo resist masks to the previously formed reference pattern, a sigma deviation from design location of the mask edge might be as high as 0.75×10^{-6} Since, the alignments of the drain region **51** and the top gate **53** are independent, the l sigma deviation from the nominal space between their edges in this example would be: $[(0.75)^2+(0.75)^2]^{0.5}=1.06\times10^{-6}$.

The ON resistance of the MOSFET **90** of FIG. **3**, is the sum of the various series resistances between the drain region **51** and the source region **56**. This series resistance includes the drain region **51** and the source region **56**, plus the resistance of MOS channel **65**, the resistance of the drift region **50** (in particular the resistance of a JFET channel **67** in the drift region **50** positioned beneath the JFET channel top gate **53**) and the link resistances between the JFET channel **67** under the top gate **53** and the drain region **51** and between the JFET channel **50** under the top gate **53** and the MOS channel **65**. Thus, one term in the ON resistance, the link resistance from the JFET channel **67** to the drain region **51**, is proportional to the length of the region **92** from an edge of the top gate **53** to an adjacent edge of the drain contact **51**. This distance also increases the total device area. It is important to accurately control this length to minimize deviations in device area and ON resistance for MOSFETs constructed as illustrated in FIG. **3**.

The above-mentioned undesirable variations associated with the spacing between the drain region and the JFET top gate can be reduced in accordance with the teachings of the present invention. According to the teachings of the present invention, the distance between the drain region and the top JFET gate is set without an alignment tolerance. In addition, the present invention reduces variations in the length of region **92** without the requirement of additional mask steps, thereby minimizing fabrication costs. Moreover, the present invention provides other novel teachings as disclosed and claimed below. The elements and method steps of the present invention are represented by conventional elements in the drawings, showing only those specific details that are pertinent to the present invention, so as not to obscure the disclosure with structural details that will be readily apparent to those skilled in the art having the benefit of the description herein.

The fabrication process for a MOSFET **100** of one embodiment the present invention begins with FIG. **4**, wherein a relatively thick field dielectric or oxide layer **116** is deposited, by chemical vapor deposition or thermally grown, on the upper surface **118** of the substrate **112**. As shown in FIG. **5**, a portion of the relatively thick field oxide layer **116** is removed by etching and a drift region **119** is formed by implanting dopants into the substrate **112** using the relatively thick oxide layer **116** as a mask. Referring to FIG. **6**, the remaining portion of the thick field oxide layer **116** is removed and a dielectric layer is formed over the substrate **112**. In one embodiment, the dielectric is an oxide and the dielectric layer is referred to as an oxide layer. The oxide layer comprises a relatively thin oxide layer **120** and a thick oxide region **121**.

In one embodiment, the thin oxide layer **120** and thick oxide layer **121** are formed by a local oxidation of silicon process (LOCOS) above the drift region **110**. In particular, the

LOCOS process involves depositing silicon nitrate (nitride) over a thin oxide layer that can be referred to as the pad oxide. The nitride is then patterned and removed from areas where thick regions of oxide are to be grown. Although, not shown in the Figures, other devices formed in the integrated circuit besides the MOSFET **100** that require the formation of device regions use relatively thick regions of oxide as masks. These relatively thick regions are also formed at the same time by patterning the nitride layer in select locations. The substrate **112** is then subject to a thermal oxidation cycle which causes thick region **121** to be grown over the pad oxide as well as other thick regions beyond the MOSFET **100** device not covered by the nitride. Hence, the nitride acts as a mask in growing the thick regions of oxide during the thermal oxidation cycle. Once the thick regions of oxide have been grown, which include thick region **121**, the remaining nitride and underlying pad oxide **120** are removed. The thin oxide layer **120** is then grown on the exposed surface **118** of the substrate **112** to form the structure as illustrated in FIG. **6**.

In an alternative embodiment, the drift region **119** (drain extension **119**) is formed using a mask before the thick oxide region **121** is formed. In this embodiment, after the drift region is formed, a layer of relatively thick oxide **116** is deposited over the entire surface **118** of the substrate **112**. This is similar to that illustrated in FIG. **4**. Portions of the thick oxide layer **116** are then removed to form the thick region **121**. Other thick regions of oxide are also formed at this time for use in forming device regions for other devices in the integrated circuit (not shown). Moreover, these other thick regions (not shown) can be used as masks to define the region comprising the MOSFET **100**. Thereafter, the thin oxide layer **120** is grown. In one embodiment, the thin oxide layer **120** is formed by oxidation of the substrate **112**. The net result of this embodiment is illustrated in FIG. **6**.

As shown in FIG. **7**, a poly silicon MOSFET gate **124** is deposited overlying a portion of the relatively thin region **120**. The MOSFET gate **124** can be referred to as a gate **124**, a gate electrode **124** or as gate material **124**. A P type body **128** is formed by masking the remainder of the MOSFET **100** and implanting P type dopants through the thin oxide **120** using the left edge of gate **124** as a self-aligned masked edge.

Referring to FIG. **8**, a drain region **130** and a source region **132** are formed. The drain region **130** and the source region **132** are formed by implanting N+ dopants through the thin oxide layer **120**. In particular, a second edge **152** of thick region **121** serves as a self-aligned mask during formation of the drain region **130** to form a first edge **170** of the drain region **130** and a photo resist mask is used to define a second edge **172** of the drain region **130**. In addition, a first edge **160** of MOSFET gate **124** serves as a self-aligned mask during formation of the source region **132** to form a second edge **182** of the source region **132** and the photo resist mask is used to define a first edge **180** of the source region **132**. Typically, the drain region **130** and the source region **132** are formed at the same time. FIG. **8** also illustrates a MOS channel region **133** within the P body **128**.

As shown in FIG. **9**, a P+ body contact **138** is formed in the P body **128** by implanting high density P type dopants through the thin oxide layer **120**. It is known by those skilled in the art that the source and drain regions **132** and **130**, respectively, can be formed either before or after formation of the P+ body contact **138**. A P type dopant is implanted through the thin oxide layer **120** to form the top gate **140**. A second edge **162** of the MOSFET gate **124** and the first edge **150** of the relatively thick region **121** serve as self-aligned mask edges for forming the top gate **140**. The width of the thick oxide region **121** is established to create the desired lateral spacing between the top gate **140** and the drain region **130**.

Referring to FIG. **10**, a second layer of dielectric **125** is deposited on the substrate **112** to provide another insulation layer. In one embodiment the second layer of dielectric is a second layer of oxide **125**. Selected regions of the relatively thin oxide layer **120** and the second layer of oxide **125** are etched and removed to form a first opening **127** adjacent the body **128** and source **132** and a second opening **129** adjacent the drain contact **130**. As illustrated in FIG. **10**A, a body-source metal conductor **131** is formed in the first opening **127** and a drain contact conductor **133** is formed in the second opening **129**. In one embodiment, the body-source metal conductor **131** and the drain contact conductor **133** are made of Aluminum. Also illustrated, is a protective layer of passivation **135** formed over the MOSFET **100**.

The MOSFET **100** of FIG. **10**, operates like MOSFET **90** of FIG. **3**. In particular, the top gate **140** functions as a JFET top gate as does the top gate **53** of FIG. **3**. Moreover, region **142** of the substrate **112** serves as the JFET bottom gate **66** of FIG. **3**. The process according to the present invention for creating the top gate **140** allows for accurate control of the distance **148** shown in FIG. **10** without the requirement for mask alignment tolerances and with few or no additional masking steps.

In another embodiment of the process according to the present invention, MOSFET **200** is fabricated. A relatively thick oxide layer **214** is first formed overlying a substrate **212**, as illustrated in FIG. **11**. The field oxide layer **214** is patterned using conventional etch processes, to create a relatively thick oxide region **218**, as illustrated in FIG. **12**. Two drain drift regions **220** and **222** (or n type regions **220** and **222**) are formed by implanting n type dopants into the substrate. In this embodiment, the space between the first drift region **220** and the second drift region **222** is generally defined by the width of the relatively thick oxide region **218**. In one embodiment, drift regions **220** and **222** are formed by masked diffusion. In this embodiment, during this diffusion process, the dopants diffuse laterally from the N type regions **220** and **222**, creating an overlap region **223** (or third N region **223**) below the relatively thick oxide region **218**, as illustrated in FIG. **12**. This creates a single main drain drift region **220**, **222** and **233** that extends from a gate electrode **230** past a drain contact **240**. This is illustrated in FIG. **15**. The drain contact **240** can be referred to as a drain region **240**.

Since, the dopant concentration in the overlap region **223** is created by lateral diffusion, it has a lower dopant concentration than that in the n-type drift regions **220** and **222**. Overlap region **223** therefore introduce an undesirable region of high resistance within drift regions **220** and **222**. In one embodiment, this resistance is reduced by adding a N region **260**, as illustrated in FIG. **13**. The overlap region **223** is positioned within the N region **260** as illustrated. Preferably N region **260** is one N well of several N wells formed at different locations within the integrated circuit. Low voltage PMOS devices may then later be formed in these other N wells in the integrated circuit. In this way, N region **260** can be formed simultaneously with the formation of PMOS wells at other locations in the integrated circuit. N region **260** is formed prior to the formation of drift regions **220** and **222**.

As also shown in FIG. **13**, a relatively thin oxide layer **226** is then grown on the substrate **212**, which, as is know by those skilled in the art, also causes the thick region **218** to grow thicker, but at a slower rate than the growth of new oxide. Referring to FIG. **14**, a gate **230** is formed over a region of the relatively thin oxide layer **226**. P type dopants are implanted

and diffused through the relatively thin oxide layer **226** to form a P type body region **232** in the P− substrate **212**.

Referring to FIG. **15**, a N+ drain region **240** and a N+ source region **244** are formed by an implant of N+ dopants through the relatively thin oxide region **226**. In particular, a mask is used in forming a second edge **292** of the N+ drain region **240** and a first edge **290** of the N+ drain region is formed by the use of a second edge **282** of the relatively thick oxide region **218** as a self-aligned mask. In addition, a mask is used to form a first edge **274** of the N+ source region **244** and a first edge **270** of gate **230** is used as a self-aligned mask to form a second edge **276** of the N+ source region **244**. As illustrated in FIG. **16**, a P+ body contact region **250** is formed in the P body region **232** by implanting P+ dopants through the relatively thin oxide layer **226**.

A P type top gate **250** is formed by an implant of P type dopants through the relatively thin oxide layer **226**. The top gate **250** is illustrated in FIG. **17**. The top gate **250** is self-aligning to the first edge **280** of the relatively thick oxide region **218** and the second edge **272** of the gate **230**.

Referring to FIG. **18**, a second layer of dielectric **251** is deposited on the substrate **212** to provide another layer of insulation. In one embodiment, the second layer of dielectric **251** is a second layer of oxide **251**. Selected regions of the relatively thin oxide layer **226** and the second layer of oxide **251** are etched and removed to from a first opening **253** adjacent the body **232** and the source **244** and a second opening **255** adjacent the drain contact **240**. A body-source conductor **257** is formed in the first opening **253** and a drain conductor **259** is formed in the second opening **255**. In one embodiment, the body-source conductor **257** and the drain conductor **259** are made of Aluminum. Also illustrated is a protective layer of passivation **261** formed over MOSFET **200**.

Referring to FIG. **18**A, MOSFET **200** is illustrated a configuration typically formed in an integrated circuit structure. In particular, FIG. **18**A illustrates two strips of a single multistripe device in an integrated circuit. The N+ drain region **240** is a centerline **261** for adjacent top gates **250** and **250**A. In this embodiment, a second thick region **219** is formed to define the distance between the drain contact **240** and top gate **250**A the same way, and at the same time, the first relatively thick region **218** is formed. As illustrated, drift region **220** is masked by the second thick region **219**. However, when the N type dopents are introduced into the substrate **212** and diffused, overlap drift region **225** under the second thick region **219** and drift region **227** are formed, thereby creating a continuous single drift region that comprises drift regions **222**, **223**, **220**, **225** and **227**.

In one embodiment, the high resistance within overlap regions **223** and **225** is reduced by adding a well **260** (or N region **260**) of the second conductivity type in the substrate, as illustrated in FIG. **18**A. In this embodiment, well **260** extends from top gate **250** to top gate **250**A. Well **260** is formed prior to the formation of N type regions **220**, **222** and **227**. Once well **260** is formed, the fabrication process continues with steps illustrated in FIGS. **12** through **18**.

Another embodiment of a MOSFET **300** is illustrated in FIG. **19**. In this embodiment, a JFET top gate **306**A can be accurately spaced apart from the drain region **308** using a strip of gate material. The strip of gate material is patterned to form the MOSFET gate **302**A, a first gate material layer **302**B and a second gate material layer **302**C. In one embodiment, the strip of gate material **302**(A-C) comprises poly silicon. Gate material layers **302**B and **302**C serve as masks for the opposing edges of the drain region **308** and gate layers **302**A and **302**B serve as masks to form the JFET top gate **306**A. In one embodiment, a drain lateral extension **318** is formed, followed by formation of gate material layers **302**(A-C). Gate material layers **302**B and **302**C can be left floating so that their potential is determined by capacitive coupling to adjacent metal layers, or alternatively, they can be connected to the drain region **308**. This biasing of the gate material layers **302**A and **302**B, reduces degradation of breakdown of the MOSFET **300**.

Following formation of gate material layers **302**(A-C), processing continues with the various fabrication steps illustrated in FIGS. **7** through **10**. As illustrated in FIG. **19**, the MOSFET **300** also includes a substrate **316**, a drift region **318**, a body region **314**, a body contact **312** and a relatively thin layer of dielectric **310**. In one embodiment, the layer of dielectric **310** is a relatively thin layer of gate oxide **310**. In addition, to minimize the area consumed by the gate material layers **300**(A-C) in an integrated circuit, the source and drain regions **304** and **308** are typically constructed in alternating opposed orientations such that a centerline **322** of a multi-striped device passes through drain region **308**. Thus, with respect to FIG. **19**, for a first strip of the device to the left of the centerline **322**, drain region **308** is associated with top gate **306**A and source region **304**. For a second strip of the device to the right of the centerline **322**, drain region **308** is associated with top gate **306**B. Moreover, the second strip of the device to the right of the centerline **322** will also have an associated source region (not shown) to the right of top gate **306**B.

With the fabrication process utilizing the gate material layers **302**(A-C), two alignment tolerances are removed from the process. Since, gate **302**A and gate material layers **302**B and **302**C are formed simultaneously by a single mask, the length of top gate **306**A is established by the distance between gate **302**A and gate material layer **300**B. Further, the width of the gate material layer **302**B determines the spacing between the top gate **306**A and the drain region **308**. Thus two alignment tolerances have been removed and the need for a separate masking step to space the top gate **306**A from the drain region **308** has been eliminated. Moreover, in one embodiment, a strip of gate material can also be utilized in lieu of the thickened oxide region **218** of FIG. **12**, to form N type regions **220** and **222** in MOSFET **300**.

In yet another embodiment of the invention, the need for a specific masking step to form the JFET top gate **306**A can be avoided by selective design of the drain region **308**, source region **304** and the JFET top gate **306**A. That is, a mask used to prevent the implantation of dopants used to form top gate **306**A in other areas of the substrate **316** can be eliminated by selective design. In particular, when drain region **308** and source region **304** are formed deeper than the top gate **306**A and also have a higher doping density at every depth than the top gate **306**A, then a mask is not required to form the latter. This is illustrated in FIG. **19**A. With this embodiment, the P type implant for forming the top gate **306**A can be permitted to diffuse into the drain region **308** and the source region **304**, where it will be overcompensated by the heavier and deeper N+ concentration. If the top gate **306**A is formed deeper than the drain region **308** and the source region **304**, and is permitted to diffuse into the drain region **308**, then the P diffusion will form a P type layer under the N+ drain region **308**. Thus the N+ drain region **308** is isolated from the drain lateral extension **318**, to which it must be ohmicly connected. Using this alternative process to form the drain region **318** and the top gate **306**A, eliminates one masked step from the fabrication sequence for the MOSFET device **300**. This embodiment can also be applied to MOSFET **100** of FIG. **10** and MOSFET **200** of FIG. **18**A.

Referring back to FIG. **19**, gate material layers **302**B and **302**C are illustrated as two separate areas. In one embodiment, however, a single gate material region **313** is formed in an elliptical shape having a center opening **309**. In this embodiment, the gate material region **313** includes gate material layers **302**B and **302**C. This is illustrated in FIG. **19**B. FIG. **19**B is a top view of one embodiment of MOSFET **300**. As illustrated, the gate material region **313** is used to define the drain region **308**. That is, the drain region **308** is defined by an inner perimeter **323** of gate material **313**. In addition, gate material **313** defines the lateral space between the top gate **317** (which includes top gates **306**A and **306**B) and the drain region **308**. Also illustrated in the embodiment of FIG. **19**B, is the drain region **308** being shared on two sides by gates **302**A, source regions **304** and body regions **314**. Moreover, FIG. **19**B also illustrates the top gate **317** extending around an outside or outer perimeter **321** of gate material layers **302**A and **302**C (or gate material region **313**). FIG. **19**B also illustrates additional areas of top gate **303** that are present in the embodiment of FIG. **19**A (the embodiment that does not require a separate mask to form the top gate **306**A). In one embodiment, a relatively thick oxide layer is used in place of the gate material in gate material region **313**. FIG. **19**B also illustrates a relatively thick oxide region **383** surrounding MOSFET **300**.

A top view of another embodiment of MOSFET **300** is illustrated in FIG. **19**C. In this embodiment, gate material region **381** includes gate material layers **302**B and **302** C. In this embodiment the gate material region **381** is formed in striped shape. Gate material region **381** has a center opening **309** that defines the drain region **308**. Moreover, the gate material region **381** defines the lateral distance between the drain region **308** and the top gates **306**A. Also illustrated in FIG. **19**C are gates **302**A, source regions **304** and body regions **314**. In yet another embodiment, a relatively thick oxide layer is patterned and used in place of the gate material in gate material region **381**. FIG. **19**C also illustrates a relatively thick oxide region **383** surrounding MOSFET **300**.

As is known by those skilled in the art, there are many applications in integrated circuits for the MOSFETs **100**, **200** and **300** described herein. For example, they can be used as linear switches, solid state relays and telecommunications switching circuits. In such applications, two DMOSFET devices have their sources connected directly or through current limiting resistors and their drains serve as the output terminals of the switch.

An embodiment of a solid state relay circuit **500** using a pair of DMOSFET devices **502** and **504** as described above, is illustrated in FIG. **20**. As illustrated, the solid state relay circuit **500** includes a photo diode stack **506**, a turn off and gate protection circuit **508** and two DMOSFET devices **502** and **504** in an integrated circuit. The photo diode stack **506** is used to drive voltage to the source S and gate G of each DMOSFET **502** and **504**. Generally, the photo diode stack **506** is illuminated by a light emitting diode (not shown). The turn off and gate protection circuit **508** is coupled in parallel with the photo diode stack **506** to discharge any gate-source capacitance when the photo diode is not driving voltage to the source S and gate G of each DMOSFET **502** and **504**. As illustrated, drain D of DMOSFET **502** is coupled to switch terminal S**0**. Moreover, drain D of DMOSFET **504** is coupled to switch terminal S**0**'.

Photo diodes in the photo diode stack **506** have open circuit voltage and a short circuit current when illuminated. A set of N photo diodes are connected in series to form the photo diode stack **506**. An open circuit voltage of the diode stack will be N times the open circuit voltage of a single photo diode. Moreover, the short circuit current of the photo diode stack **506** is equal to that of a single photo diode. Typically, an open circuit voltage of approximately 0.4V and a short circuit current of approximately 100 nA is produced by the solid state relay **500**. A load comprising the gate capacitances of the two DMOSFET devices **502** and **504** is coupled to the photo diode stack **506** in the solid state relay **500**. The gate capacitance is shunted by the turn off and gate protection circuitry **508** coupled in parallel with the photo diode stack **506**. An equilibrium gate source voltage of the DMOSFET devices **502** and **504** in an off condition is 0V.

When the light emitting diode is turned on, illuminating the photo diode stack **506**, the short circuit current of the photo diode stack **506** begins to charge the gate capacitance of DMOSFET devices **502** and **504**. A gate-source voltage of each DMOSFET devices **502** and **504** rises as the respective gate capacitance charges until reaching the stack open circuit voltage. The number of photo diodes in the photo diode stack **506** is chosen such that its open circuit voltage is larger that the threshold voltages of the DMOSFET devices **502** and **504**. Consequently, the DMOSFET devices **502** and **504** turn on when the stack is illuminated thereby presenting the ON resistance of the DMOSFET devices **502** and **504** in series with the switch terminals S**0** and S**0**'.

DMOSFET device **502** and **504** are coupled in series to form a switch to block relatively large voltages, of both polarities, across the switch terminals S**0** and S**0**' when the switch is off. This exploits the fact that the DMOSFET devices **502** and **504** each have asymmetric breakdown with the drain to source breakdown being relatively large while the source to drain breakdown is relatively small (often as small as a diode forward voltage). By having the DMOSFET devices **502** and **504** coupled in series, the drains D of the devices **502** and **504** are coupled to their associated switch terminals S**0** and S**0**'. When switch terminal S**0** has a positive voltage that is more positive than the voltage on switch terminal S**0**', the drain junction of the DMOSFET device **502** blocks the applied voltage. Moreover, when switch terminal S**0**' has a positive voltage that is more positive that the voltage on switch terminal S**0**, the drain junction of DMOSFET device **504** blocks the applied voltage.

Turn off of the solid state relay **500** is initialized when the LED is turned off. An output current of the photo diode stack **506** then goes to 0V. The turn off and gate protection circuit **508**, which in its simplest form may comprise a relatively large resistor, discharges the gate capacitance of gate G of the DMOSFET devices **502** and **504** thereby taking the gate source voltage back to 0V on both DMOSFET devices **502** and **504**.

The teachings of the present invention can also be applied to the fabrication of pn junction diodes in integrated circuits that are fabricated with a diffusion region **356**, as illustrated in FIG. **21**. The embodiment illustrated in FIG. **21**, shows a substrate **348** and a pn junction diode **340** formed in substrate **348** of the integrated circuit. The pn junction diode **340** comprises a cathode contact **350** (doped N+) and two P+ anode contact regions **352** and **354** in an anode **348** (the substrate **348**). A cathode **356** and two JFET top gate regions **358** and **360** are also illustrated. As illustrated, the cathode **356** extends laterally from a portion of top gate **358** to a portion of top gate **360**. With respect to the individual P− and N type regions, they function in a manner identical to their function in the MOSFET devices discussed above.

The teachings of the present invention offer a fabrication technique that eliminates masked alignment tolerances and provides a relatively accurate length for the regions **362** and **364**, which are disposed between the cathode contact **350** and

the top gates **358** and **360**, respectively. Thus, the technique described with respect to FIGS. **4** through **10** (teaching the use of a thick oxide region as a mask, thick oxide regions **359** and **361** of FIG. **21**), FIGS. **11** through **18**A (teaching the use of two overlapping n-type diffusions to form a drift region **356**, which in this case is a N type cathode region **356**) and FIG. **19-19**A (teaching the use of a gate layer material as a mask instead of a relatively thick oxide or dielectric layer) can be applied to the structure of FIG. **21**. As is known by those skilled in the art, the structure of FIG. **21** can also be modified such that the JFET top gates **358** and **360** overlap or abut the P+ anode contact regions **352** and **354**, respectively.

Referring to FIG. **21**A a top view of one embodiment of a pn junction diode **340** is illustrated. As illustrated, in this embodiment, thick oxide region **363** includes thick oxide regions **359** and **361**. In particular, ends of the thick oxide regions **359** and **361** are connected together when formed to create a single thick oxide region **363** with a central opening **383**. In the embodiment shown, the thick oxide region **363** is formed in an elliptical shape. Moreover, thick oxide region **362** defines the cathode contact **350**. In particular an inner perimeter **385** of the thick oxide region **363** defines the cathode contact **350**. In addition, the thick oxide region **363** also defines the lateral distance between the cathode contact **350** and top gate region **355**. In this embodiment, top gate region **355** includes top gate regions **358** and **360** of FIG. **21**. That is, top gate regions **358** and **360** form the single top gate region **355**. Top gate region **355** extends around an outer perimeter **387** of the thick oxide region **355**. Also shown in FIG. **21**A are the anode contact regions **352** and **354**. In one embodiment, top gate regions **370** and **372** are also included. In addition, as illustrated, a layer of relatively thick oxide **380** surrounds the pn junction diode **340**.

The teachings of the present invention can also be applied to a high voltage PNP bipolar junction transistor **401** formed in an integrated circuit as illustrated in FIG. **22**. The transistor regions are formed in a substrate **399** of the integrated circuit and comprise a base contact **400** and an emitter **402** disposed within a base region **404**. An extension region **406** (which in one embodiment can be made shallower than the base region **404**) is also illustrated. The transistor **401** also comprises two p-type extension regions or JFET top gates **410** and **412**. The JFET top gates **410** and **412** are actually separate parts of a single gate that is formed in a semi-circular shape in the substrate **399**. A collector contact **414** is also shown. The teachings of the present inventions as discussed above can be advantageously utilized to accurately space the base region **404** from the P-type extension **410** and **412**. In particular, FIGS. **4** through **10** (which teach the use of a relatively thick dielectric region as a mask to accurately dimension the distances **416** and **418** of FIG. **22**). FIG. **22** illustrates relatively thick dielectric regions **419** and **421** of the PNP junction transistor **401**. The relatively thick dielectric regions **419** and **421** are actually separate parts of a single relatively thick dielectric region that is formed into a semi-circular shape to define the base region **404**. Other teachings of the present invention as discussed above can also be advantageously utilized in overlapping N type diffusions (as illustrated in FIGS. **11-18**A) and using of a gate material layer as a mask (as illustrated in FIGS. **19-19**A). Although FIG. **22** illustrates a PNP bipolar junction transistor **401**, those skilled in the art recognize that the teachings of the present invention can also be applied to an NPN bipolar transistor of an integrated circuit.

While the invention has been described with reference to preferred embodiments, it will be understood by those skilled in the art that various changes may be made and equivalent elements may be substituted for elements thereof without departing from the scope of the present invention. In addition, modifications may be made to the teachings of the invention to adapt it to a particular situation, without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention would include all embodiments falling within the scope of the appended claims.

What is claimed is:

[**1**. A method of forming a high voltage MOSFET for an integrated circuit, the method comprising:

forming a relatively thin layer of dielectric on a surface of a substrate;

depositing a gate material layer on the relatively thin layer of dielectric;

removing portions of the gate material layer to form first and second gate material regions of predetermined lateral lengths;

introducing a first conductivity type dopant in the substrate to form a top gate using first edges of the first and second gate material regions as masks, wherein the top gate is formed adjacent the surface of the substrate and laterally between the first and second gate material regions;

introducing a second conductivity dopant of high dopant density in the substrate to form a drain region adjacent the surface of the substrate using a second edge of the second gate material region as a mask to form a first edge of the drain region, wherein the second gate material region is positioned laterally between the drain region and the top gate; and

wherein the spaced distance between the top gate and the drain region is determined by the lateral length of the second gate material region.]

[**2**. The method of claim **1**, wherein the drain region is formed to extend deeper from the surface of the substrate than the top gate, further wherein the drain region is formed with a higher doping density at every depth than the top gate.]

[**3**. The method of claim **1**, wherein the removing of portions of the gate material layer further forms a third gate material region of a predetermined lateral length, wherein a edge of the third gate material region is used as a mask to form a second edge of the drain region.]

[**4**. The method of claim **3**, wherein the second and third gate material regions are left floating.]

[**5**. The method of claim **3**, further comprising:

coupling the second and third gate material regions to the drain region.]

[**6**. The method of claim **3**, wherein the third gate material region is connected to the second gate material region, the second and third gate material regions forming a central opening, wherein the drain region is formed through the central opening.]

[**7**. The method of claim **1**, further comprising:

introducing the second conductivity type dopant of high density to the substrate to form a source region adjacent the first gate material region, wherein the first gate material region is generally positioned laterally between the source region and the top gate.]

[**8**. The method of claim **7**, wherein an edge of the first gate material region is used as a mask to form an edge of the source region.]

[**9**. The method of claim **7**, further comprising:

introducing the first conductivity type dopant to the substrate to form a body region, the body region being positioned adjacent the surface of the substrate and the source; and

introducing a first conductivity dopant of a high density in the body region to form a body contact, wherein the body contact is positioned adjacent the surface of the substrate and a portion of the source.]

[10. The method of claim **1**, further comprising:

forming a first drift region of a second conductivity type dopant in the substrate using a first edge of the second gate material region as a mask; and

forming a second drift region of the second conductivity type dopant in the substrate using a second edge of the second gate material region as a mask.]

[11. The method of claim **10**, further comprising:

diffusing the first and second drift regions to form an overlap third region under the second gate material region.]

[12. The method of claim **10**, further comprising:

forming a well region in the substrate of the second conductivity type to reduce resistance within the first and second drift regions, wherein portions of the first and second drift regions are formed in the well.]

[13. The method of claim **10**, wherein the first and second drift regions are spaced apart from each other by the width of the second gate material region.]

[14. A method of forming a lateral MOSFET in an integrated circuit, the method comprising:

forming a drain contact of a second conductivity type with a high density dopant in a substrate adjacent a surface of the substrate;

forming a top gate of a first conductivity type in the substrate adjacent the surface of the substrate and a predetermined distance from the drain contact after the drain contact is formed; and

wherein the drain contact is formed to extend deeper from the surface of the substrate than the top gate and is formed to have a higher dopant density at every depth than the top gate so a mask is not needed to shield the drain contact from the first conductivity dopants during formation of the top gate.]

[15. The method of claim **14**, further comprising:

forming a relatively thin dielectric layer on a surface of a substrate, the substrate being of a first conductivity type with a low dopant density; and

depositing a gate on the surface on the relatively thin dielectric layer.]

[16. The method of claim **14**, further comprising:

forming a source of the second conductivity type with a high dopant density in the substrate approximate the gate, wherein the source is formed to extend deeper from the surface of the substrate than the top gate and is formed to have a higher dopant density at every depth than the top gate so a mask is not needed to shield the source from the first conductivity dopants during formation of the top gate.]

[17. The method of claim **14**, wherein forming the distance between the drain contact and the top gate further comprises:

forming a relatively thick layer of material having a predetermined lateral length on the surface of the substrate;

introducing high density dopants of the second conductivity type to the substrate to form the drain contact, wherein a first edge of the relatively thick layer of material defines a first edge of drain contact; and

introducing dopants of the first conductivity type to the substrate to form the top gate, wherein a second edge of the relatively thick layer of material defines a first edge of the top gate, further wherein the distance between the top gate and the drain contact is defined by the lateral length of the relatively thick layer of material.]

[18. The method of claim **17**, wherein the relatively thick layer of material is a layer of dielectric.]

[19. The method of claim **17**, wherein the relatively thick layer of material is a layer of gate material.]

20. A device comprising:

a substrate having a surface;

a relatively thin layer of dielectric material on the surface of the substrate;

a relatively thick layer of dielectric material on the surface of the substrate adjacent to the relatively thin layer of dielectric material;

a drain region of a first conductivity type with a higher dopant density in the substrate adjacent to the surface of the substrate; and

a drift region of the first conductivity type with a lower dopant density in the substrate adjacent to the surface of the substrate, the drift region comprising a first portion having a junction depth less than the junction depths of adjacent portions on opposite sides of the first portion.

21. The device of claim 20, wherein the first portion of the drift region has a lower dopant density than the adjacent portions on opposite sides of the first portion.

22. The device of claim 20, wherein the first portion of the drift region is located below the relatively thick layer of dielectric material.

23. The device of claim 20, wherein the first portion of the drift region comprises overlapped diffused edges of a first conductivity type dopant.

24. The device of claim 20, wherein the first portion of the drift region comprises overlapped diffused edges of a first conductivity type dopant masked by the relatively thick layer of dielectric material.

25. The device of claim 20, wherein the drain region has an edge defined by an edge of the relatively thick layer of dielectric material.

26. The device of claim 20, further comprising a gate region on the relatively thin layer of dielectric material.

27. The device of claim 20, further comprising a body region of a second conductivity type in the substrate adjacent to the surface of the substrate.

28. The device of claim 27, further comprising a source region of the first conductivity type with a higher dopant density in the body region.

29. The device of claim 28, further comprising a body contact of the second conductivity type with a higher dopant density in the body region adjacent to the source region.

30. A device comprising:

a first dielectric layer on a surface of a substrate;

a second dielectric layer on the surface of the substrate adjacent to the first dielectric layer, the second dielectric layer having a thickness greater than the thickness of the first dielectric layer;

a drain region of a first conductivity type in the substrate adjacent to the surface of the substrate; and

a drift region of the first conductivity type in the substrate adjacent to the surface of the substrate, the drift region comprising a first portion having a lower doping density than the doping densities of adjacent portions on opposite sides of the first portion.

31. The device of claim 30, further comprising a gate region on the first dielectric layer.

32. The device of claim 30, further comprising a body region of a second conductivity type in the substrate adjacent to the surface of the substrate.

33. The device of claim 32, further comprising a source region of the first conductivity type in the body region.

34. The device of claim 33, further comprising a body contact of the second conductivity type in the body region adjacent to the source region.

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