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Gopalan

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(54) **FABRICATION OF A BIPOLAR TRANSISTOR USING A SACRIFICIAL EMITTER**

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(73) Assignee: **Cypress Semiconductor Corporation**, San Jose, CA (US)

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 2 days.

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(21) Appl. No.: **10/323,002**

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Primary Examiner—Jerome Jackson

(51) **Int. Cl.**⁷ **H01L 29/737**; H01L 21/8222

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(52) **U.S. Cl.** **438/321**; 257/198

(57) **ABSTRACT**

(58) **Field of Search** 438/321; 257/198

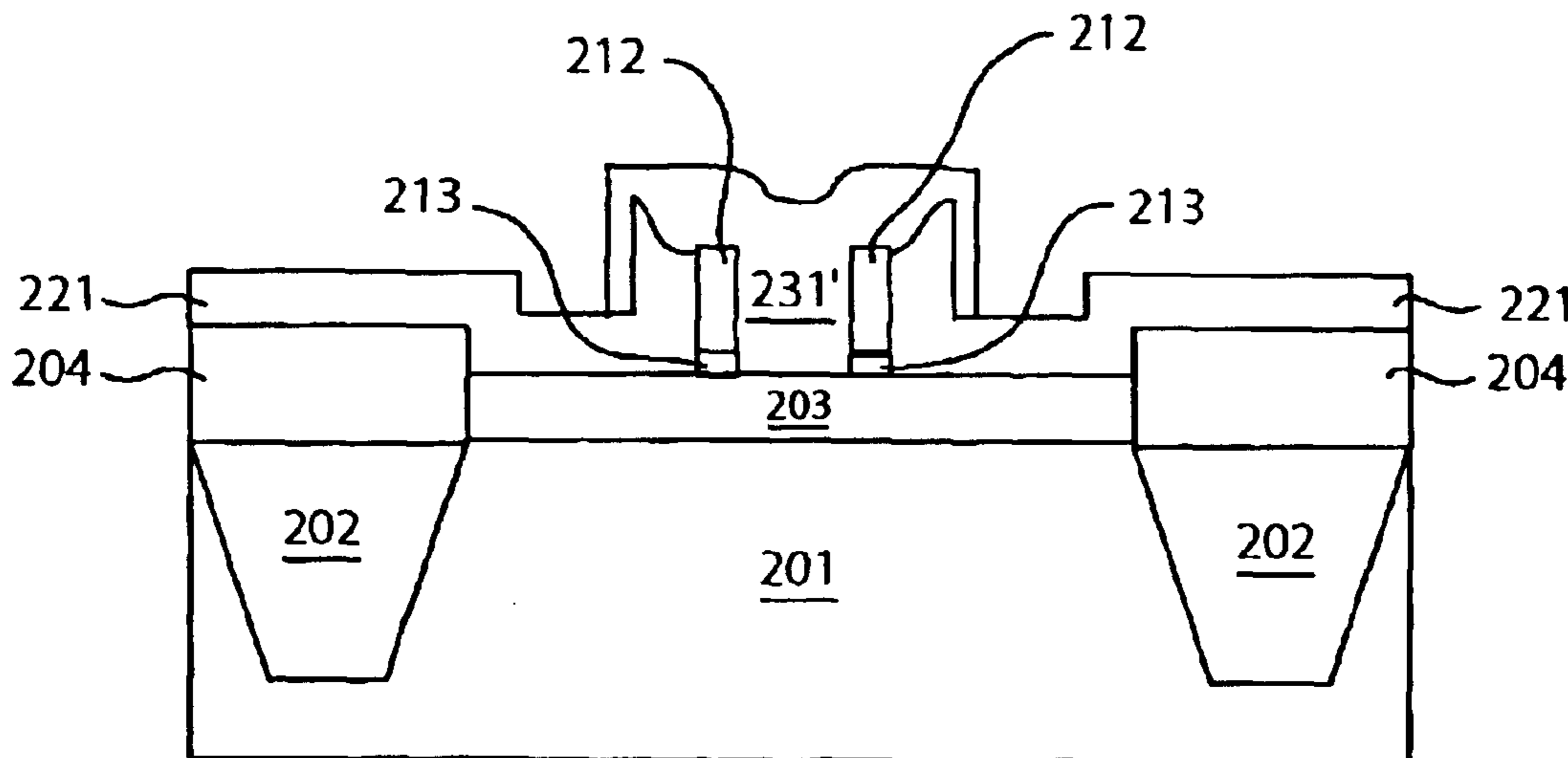
In one embodiment, a transistor is fabricated by forming a sacrificial emitter over a base, forming an oxide layer over the sacrificial emitter, removing a portion of the oxide layer, and then removing the sacrificial emitter. An emitter is later formed in the space formerly occupied by the sacrificial emitter. The sacrificial emitter allows a base implant step to be performed early in the process using a single masking step. The base may comprise epitaxial silicon-germanium or silicon.

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17 Claims, 10 Drawing Sheets



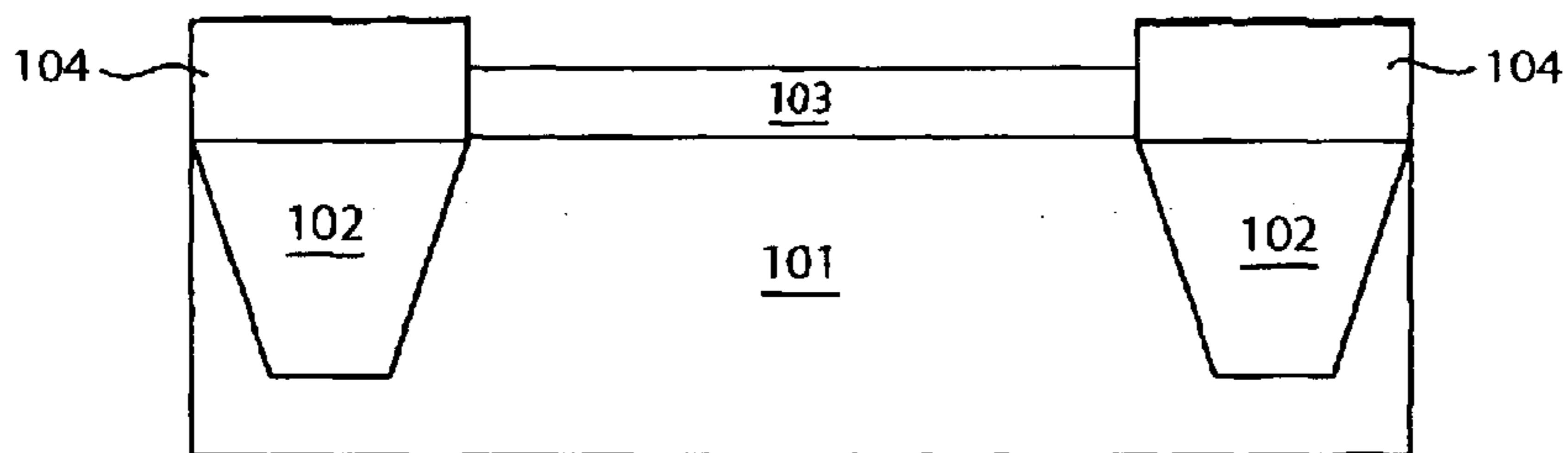


FIG. 1(a)
(Background Art)

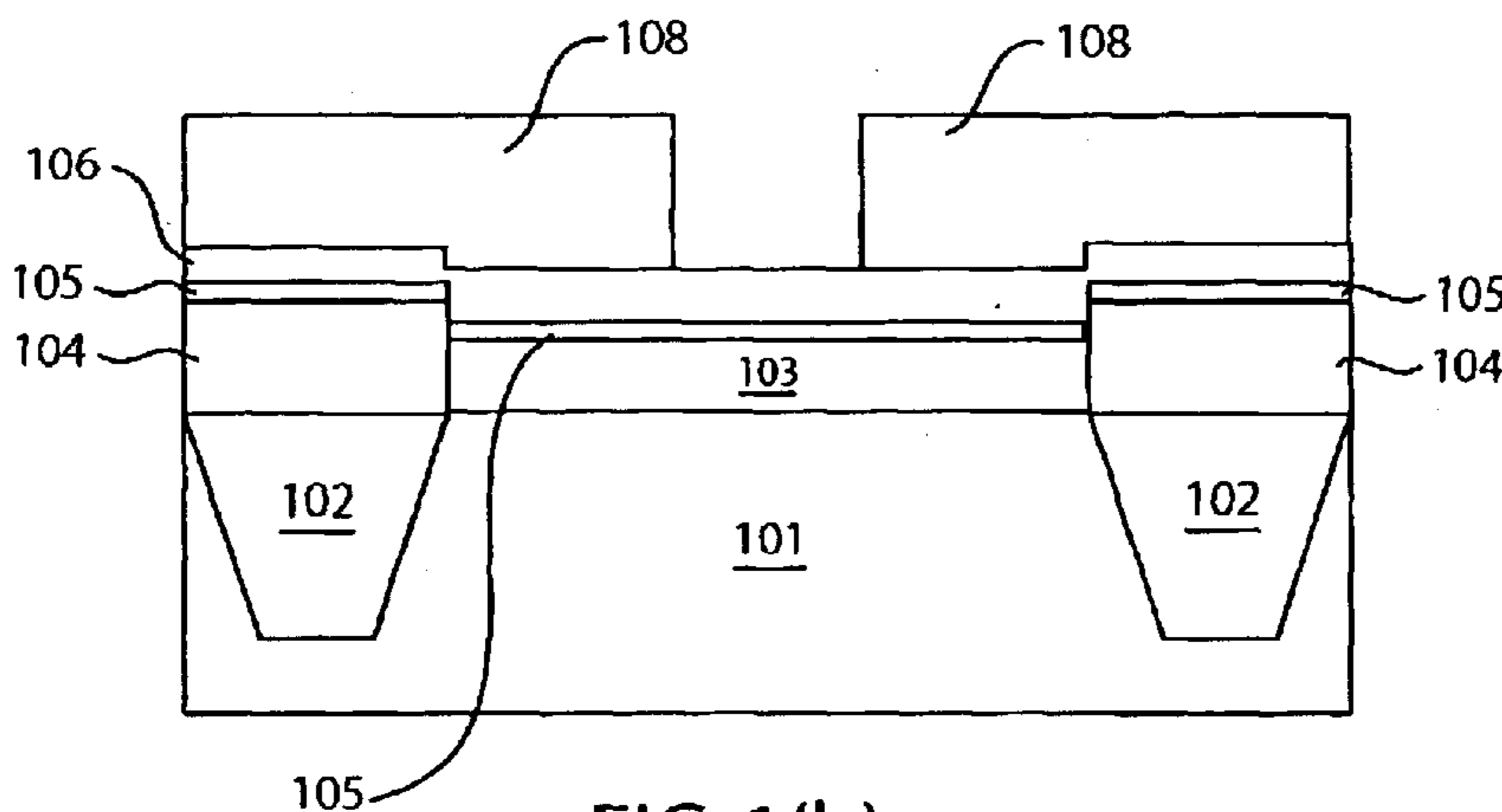


FIG. 1(b)
(Background Art)

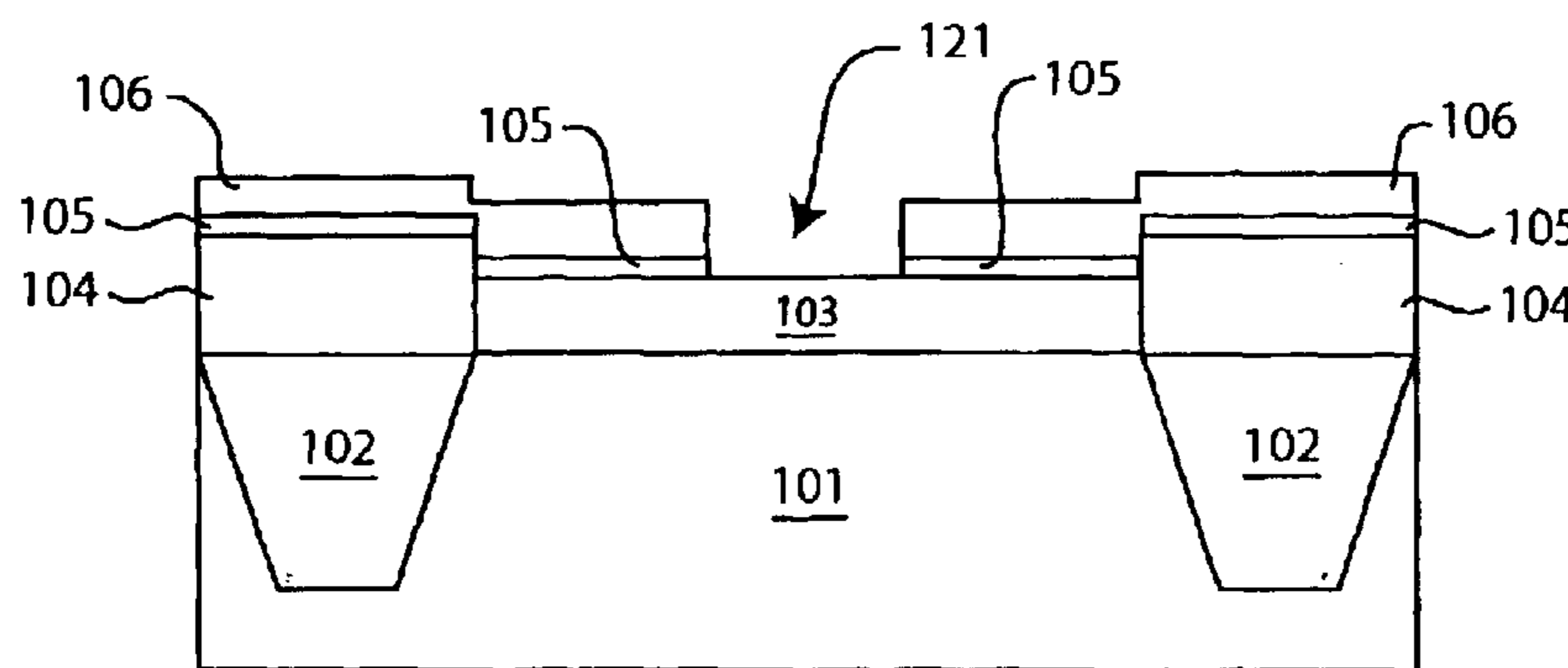


FIG. 1(c)
(Background Art)

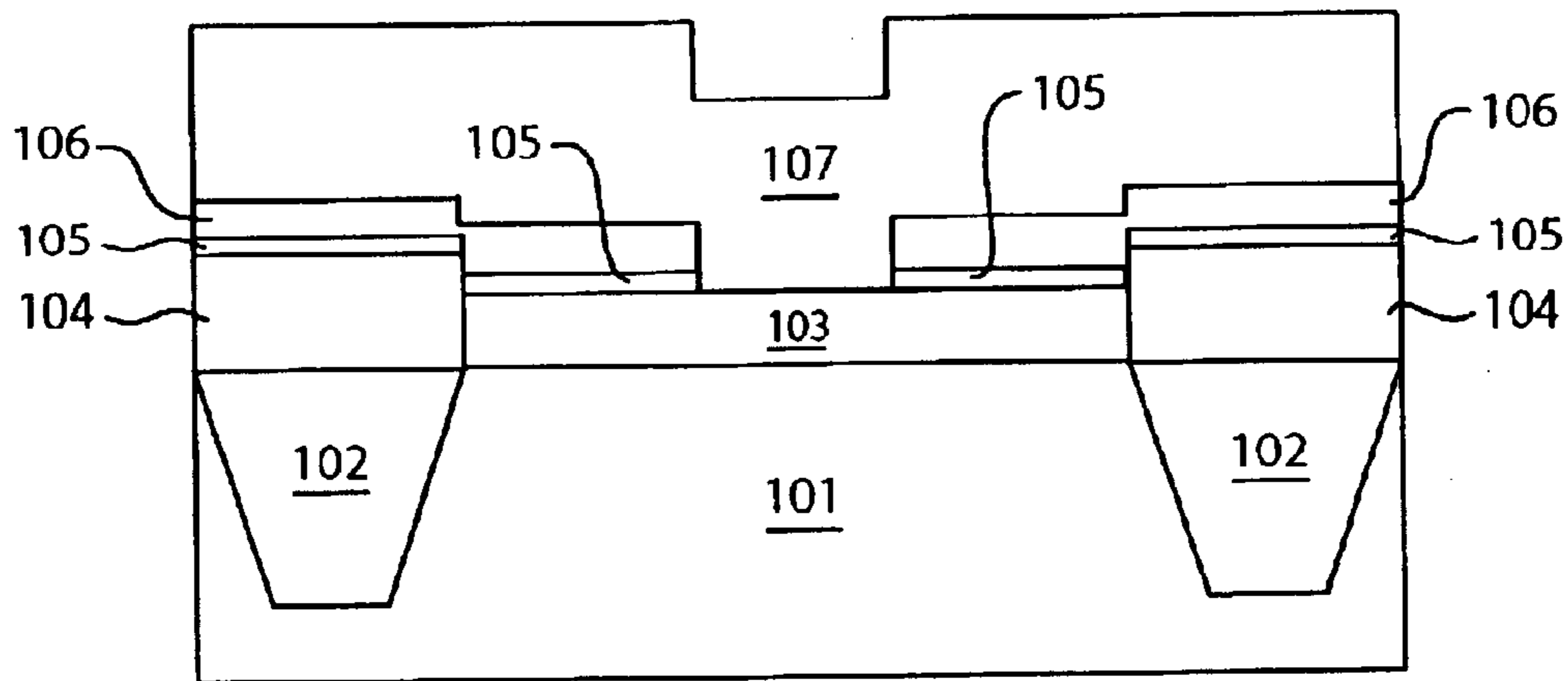


FIG. 1(d)
(Background Art)

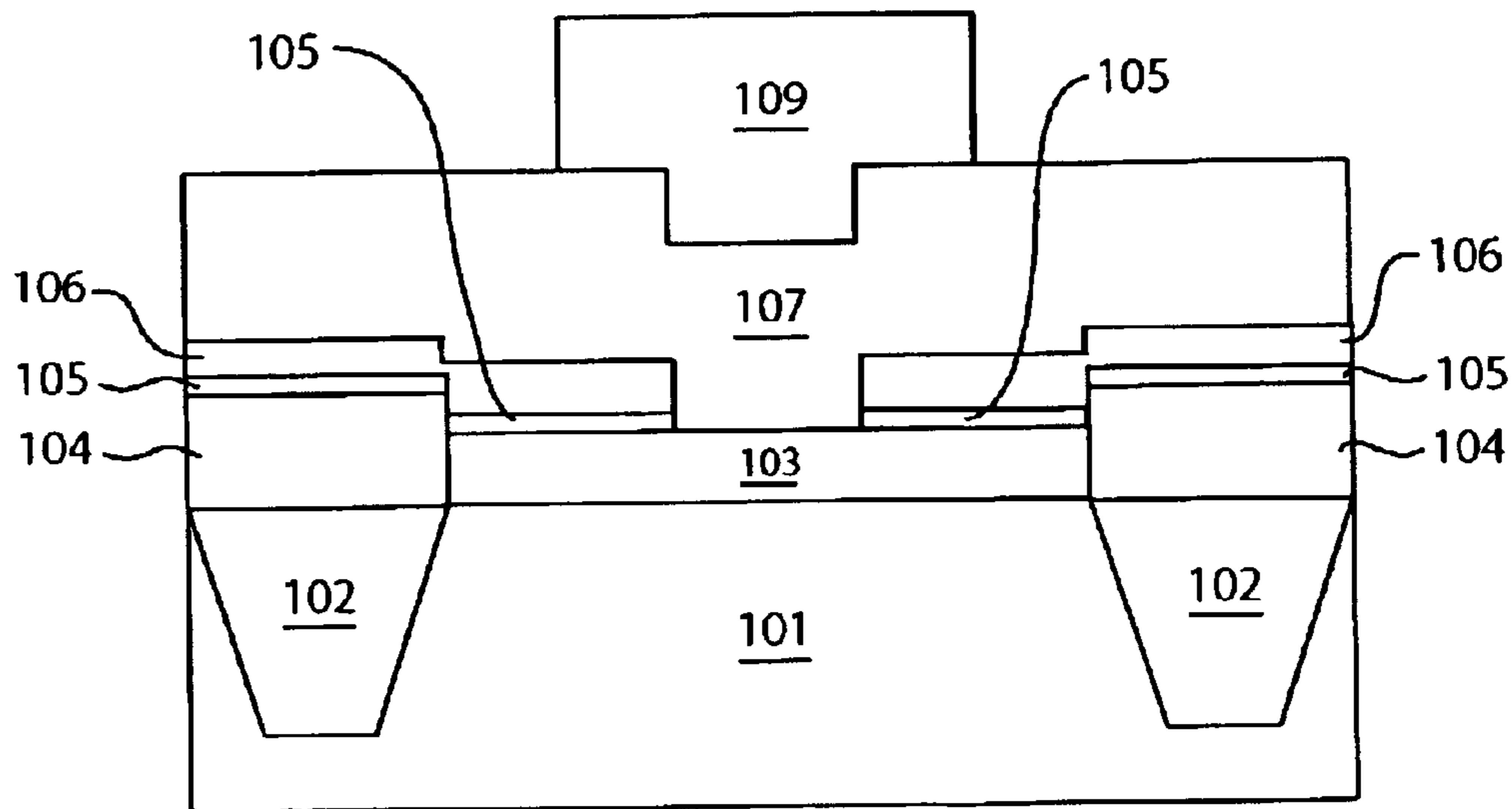


FIG. 1(e)
(Background Art)

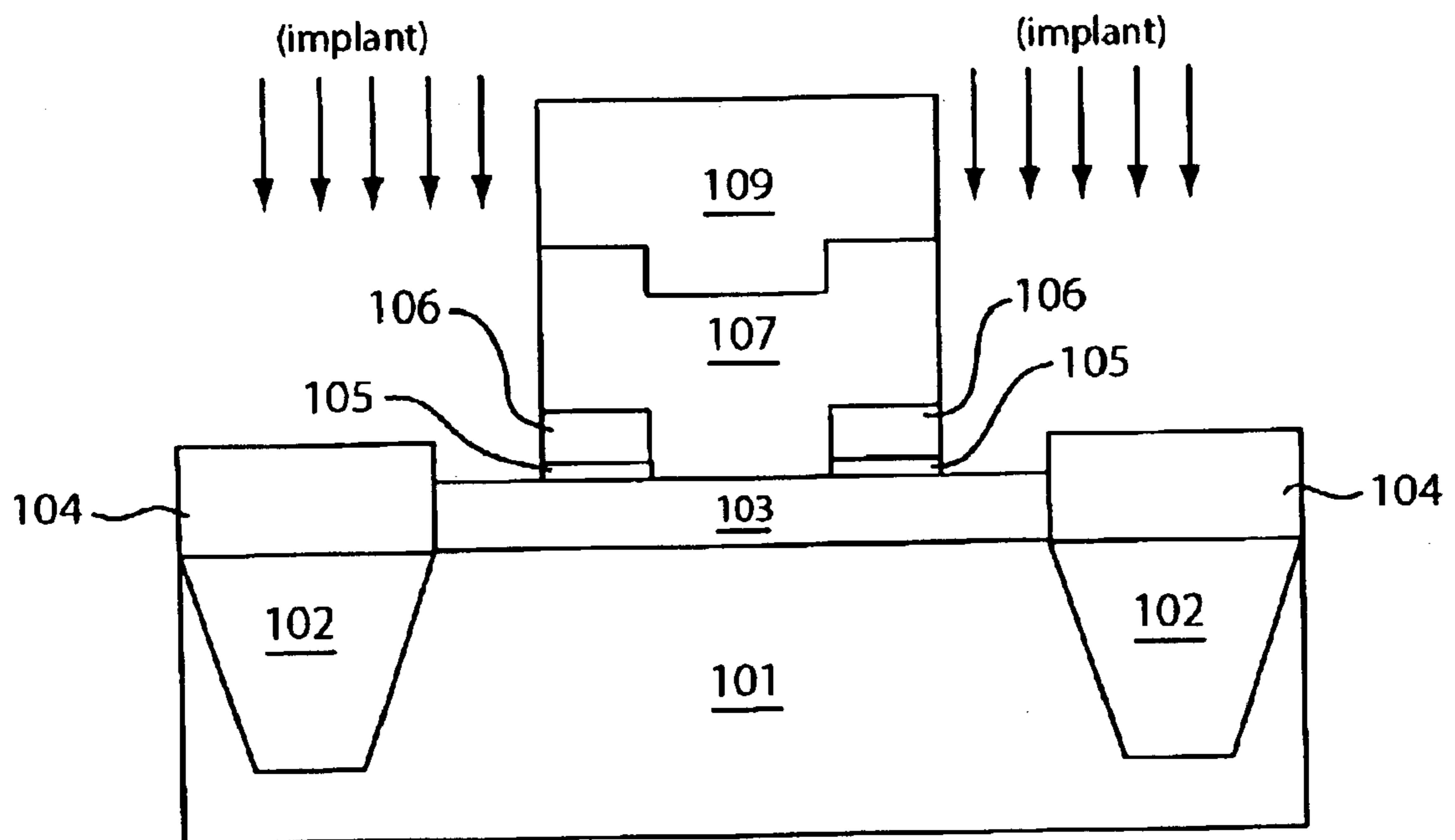


FIG. 1(f)
(Background Art)

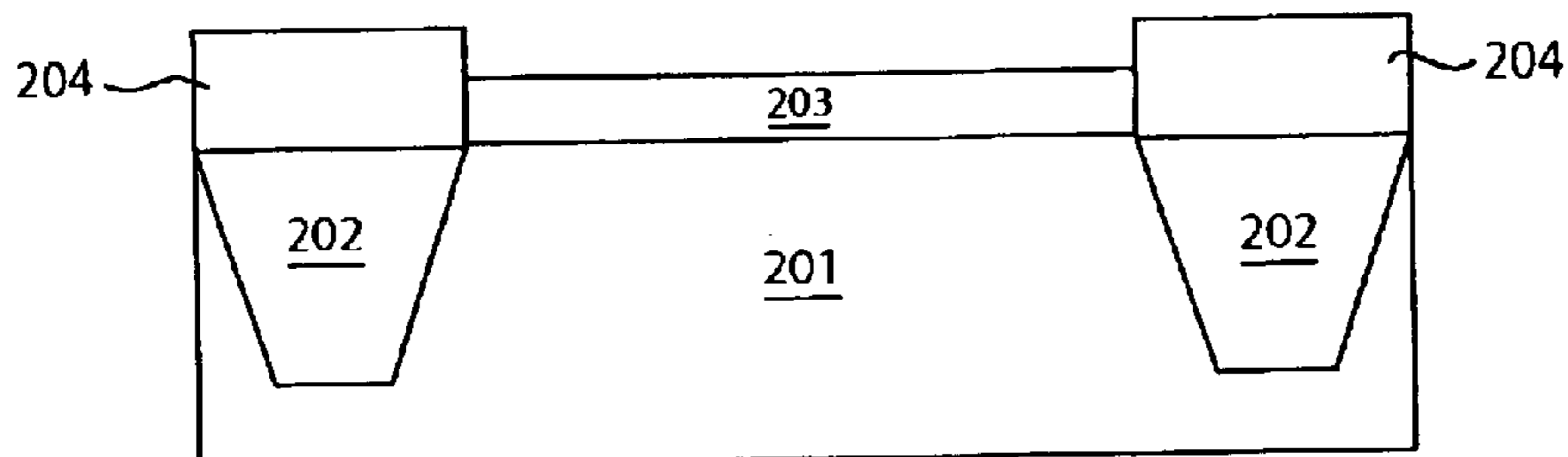


FIG. 2(a)

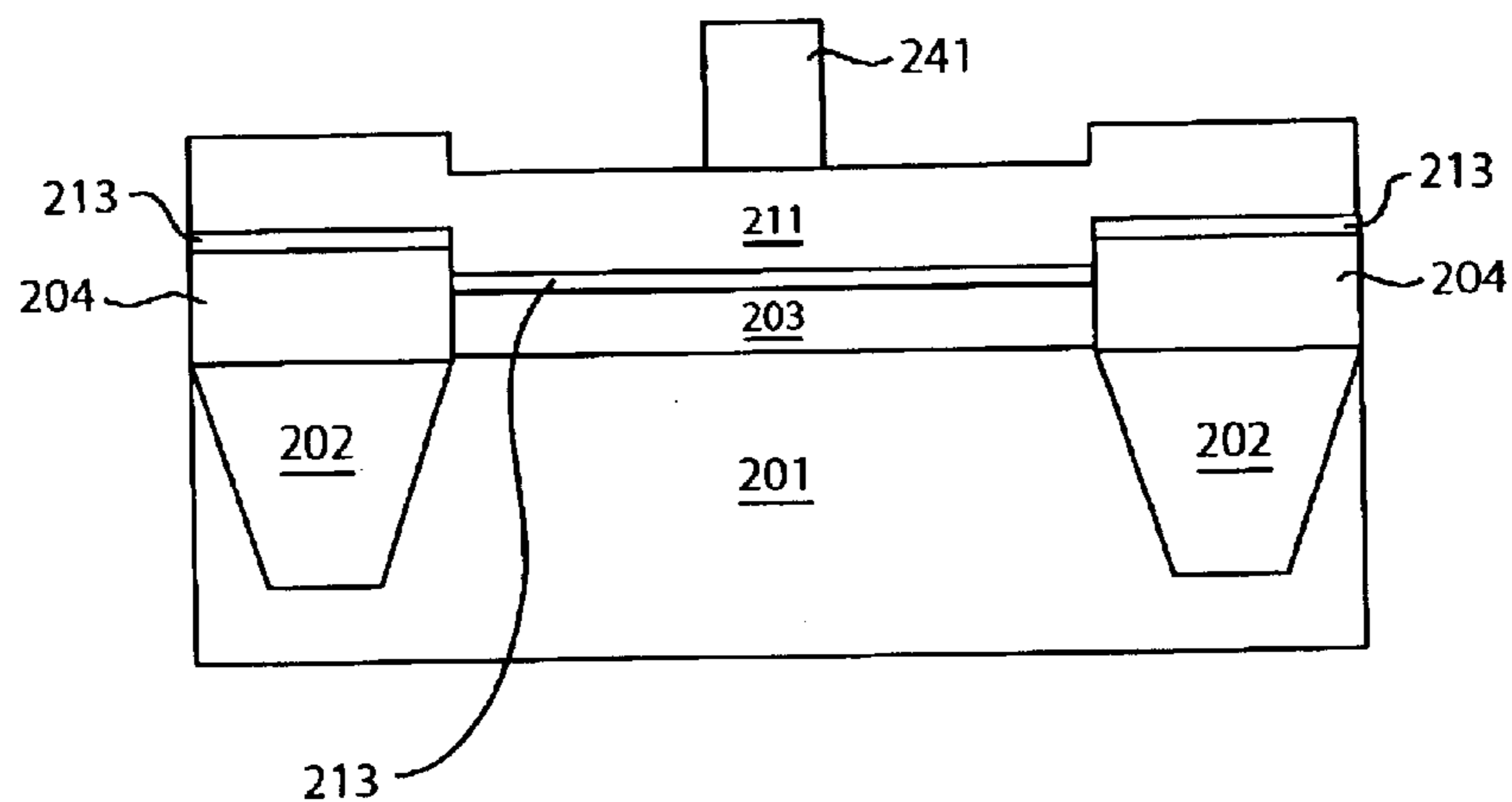


FIG. 2(b)

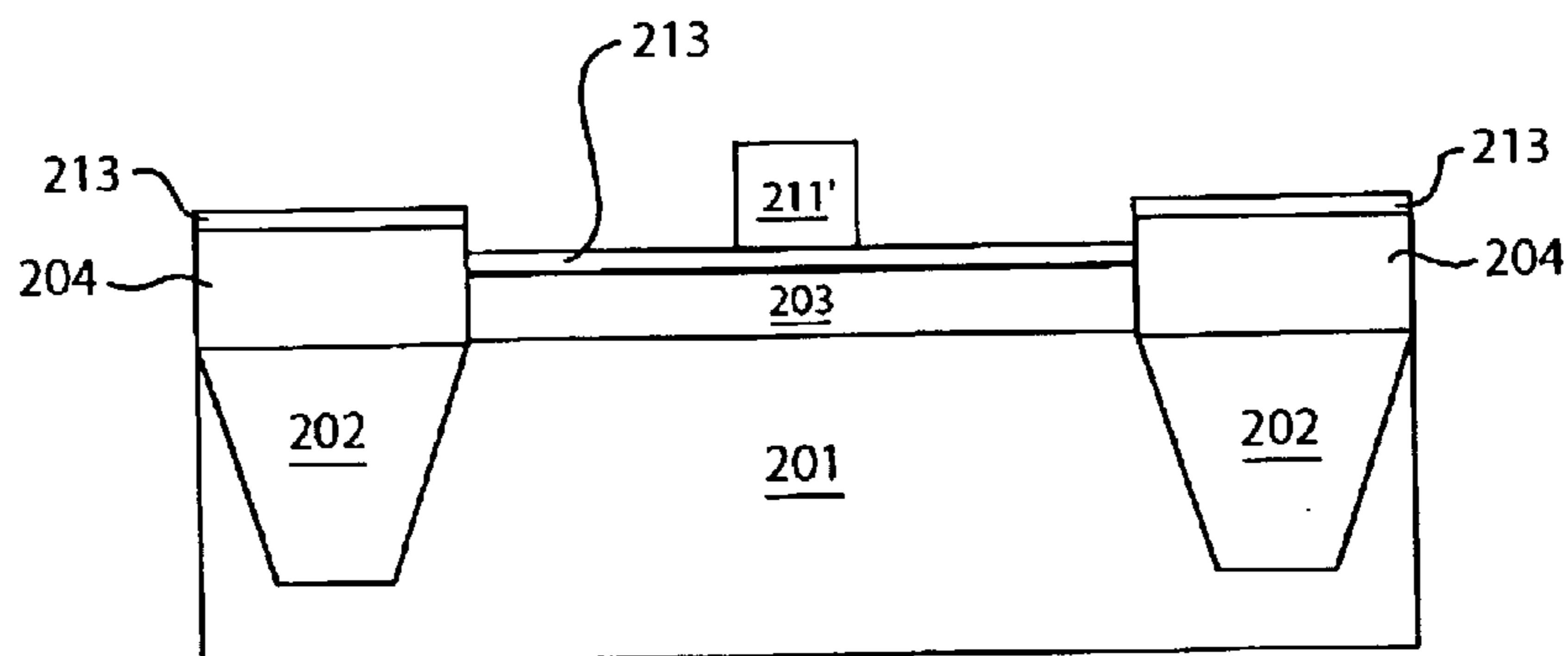


FIG. 2(c)

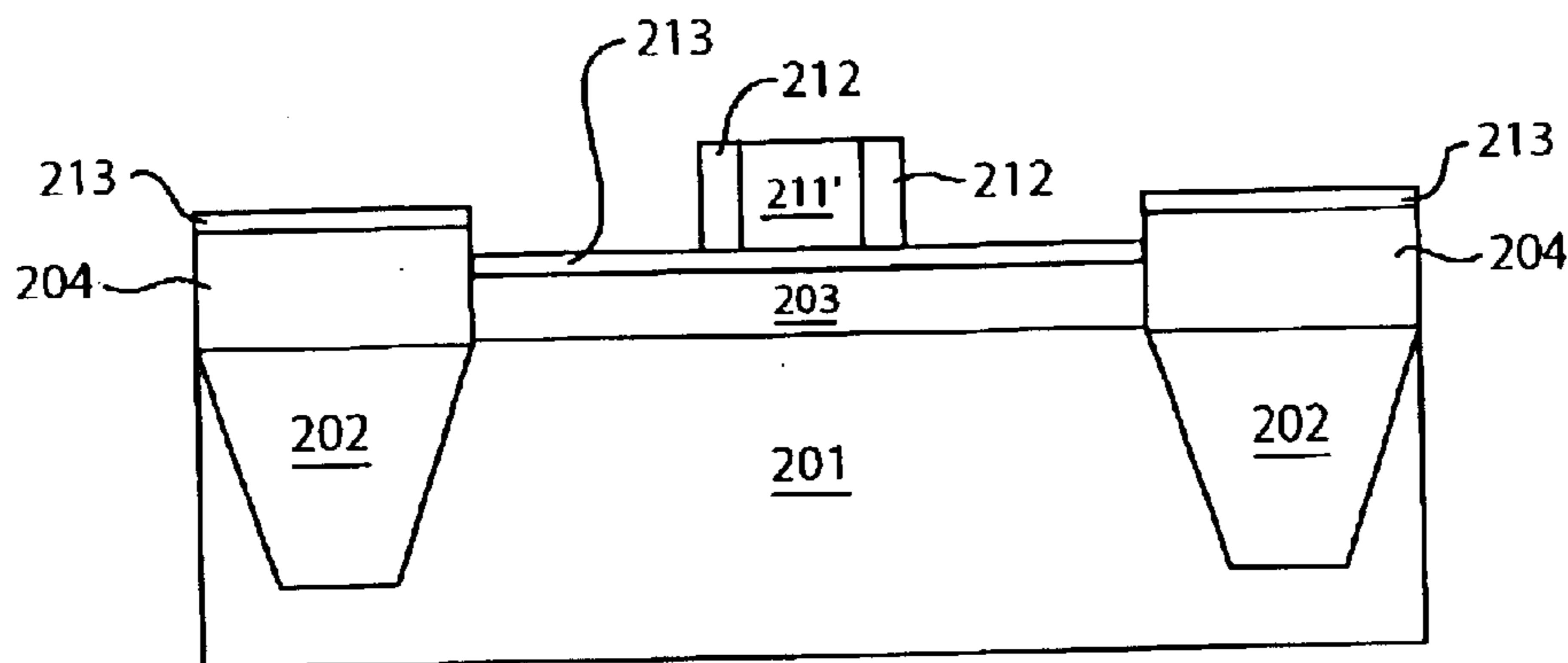


FIG. 2(d)

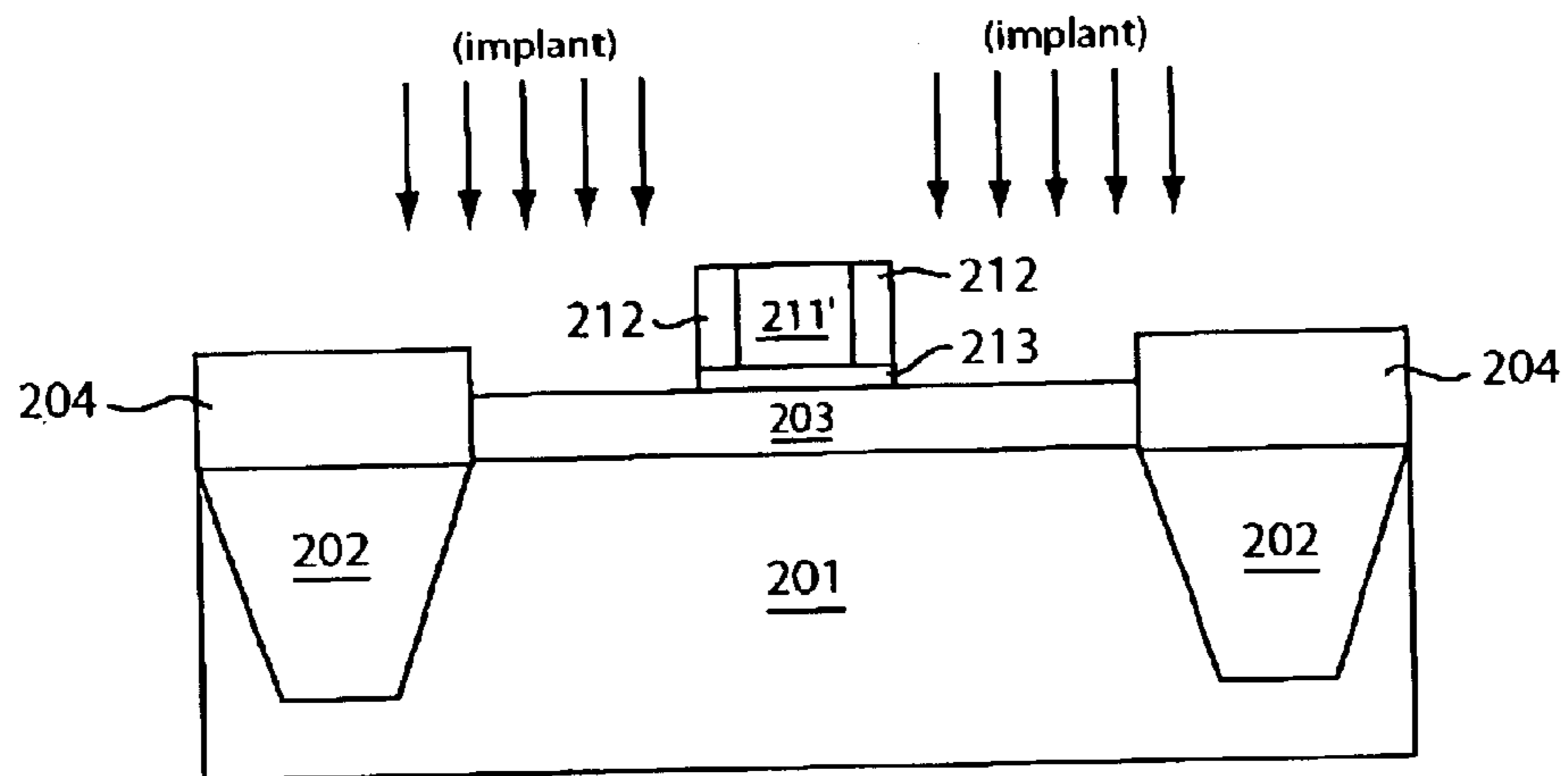


FIG. 2(e)

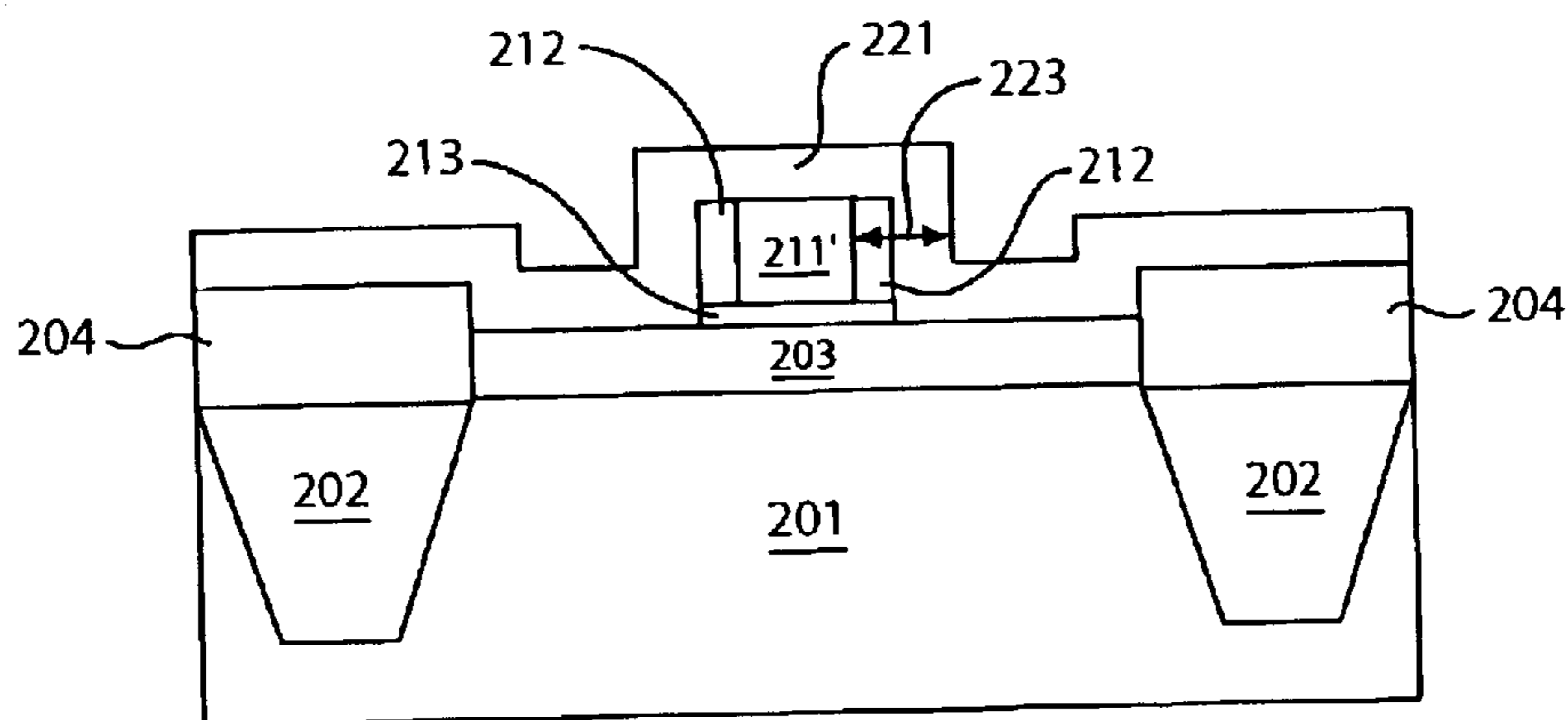


FIG. 2(f)

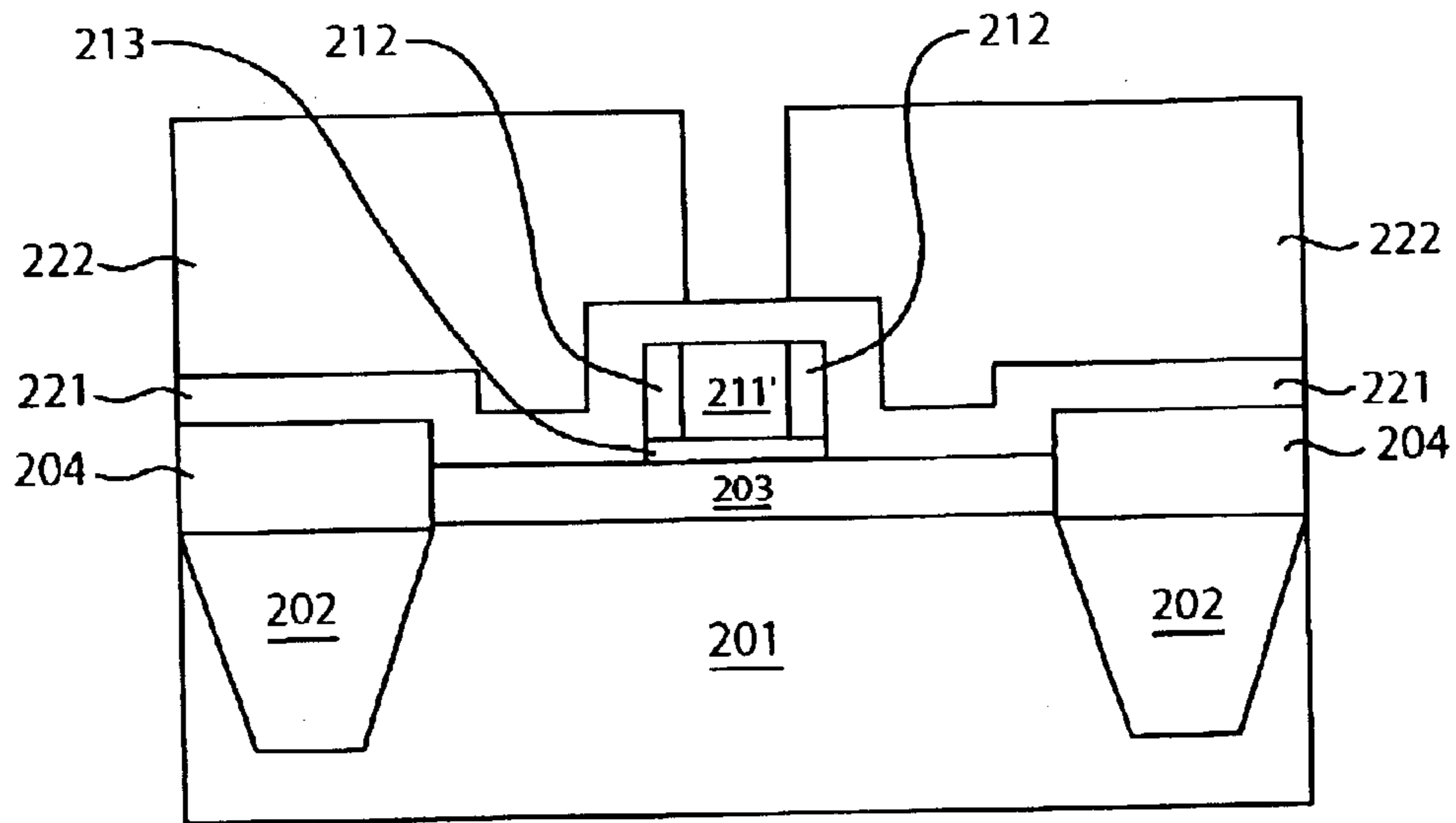


FIG. 2(g)

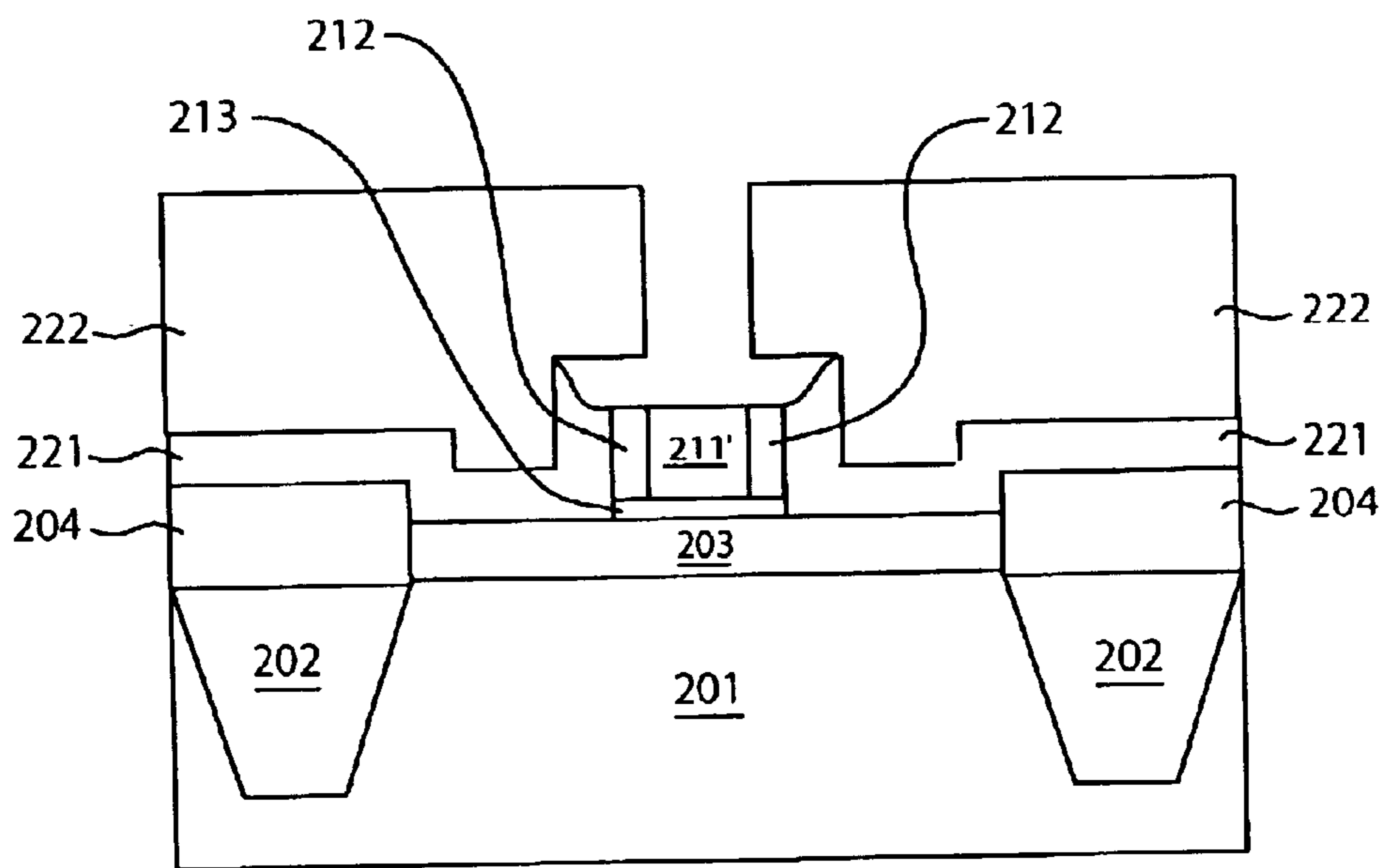


FIG. 2(h)

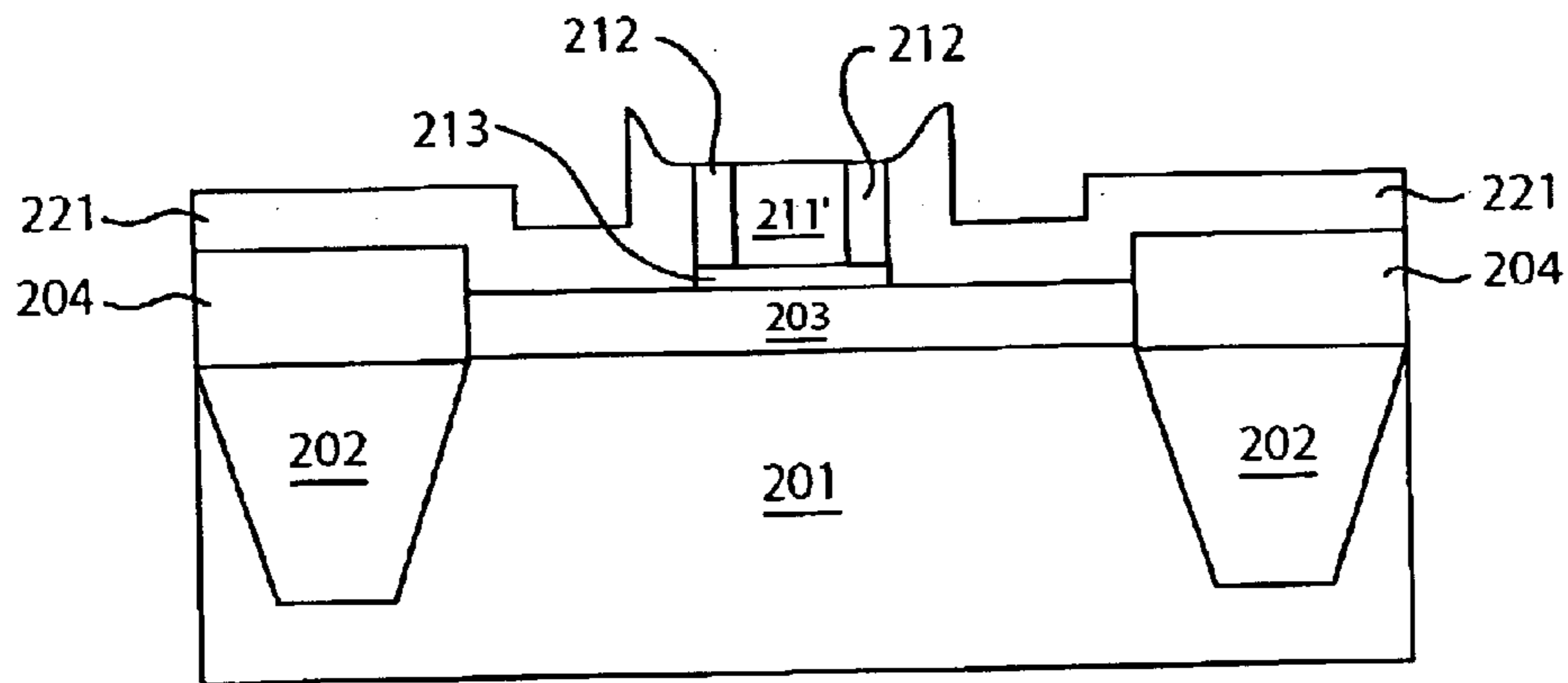


FIG. 2(i)

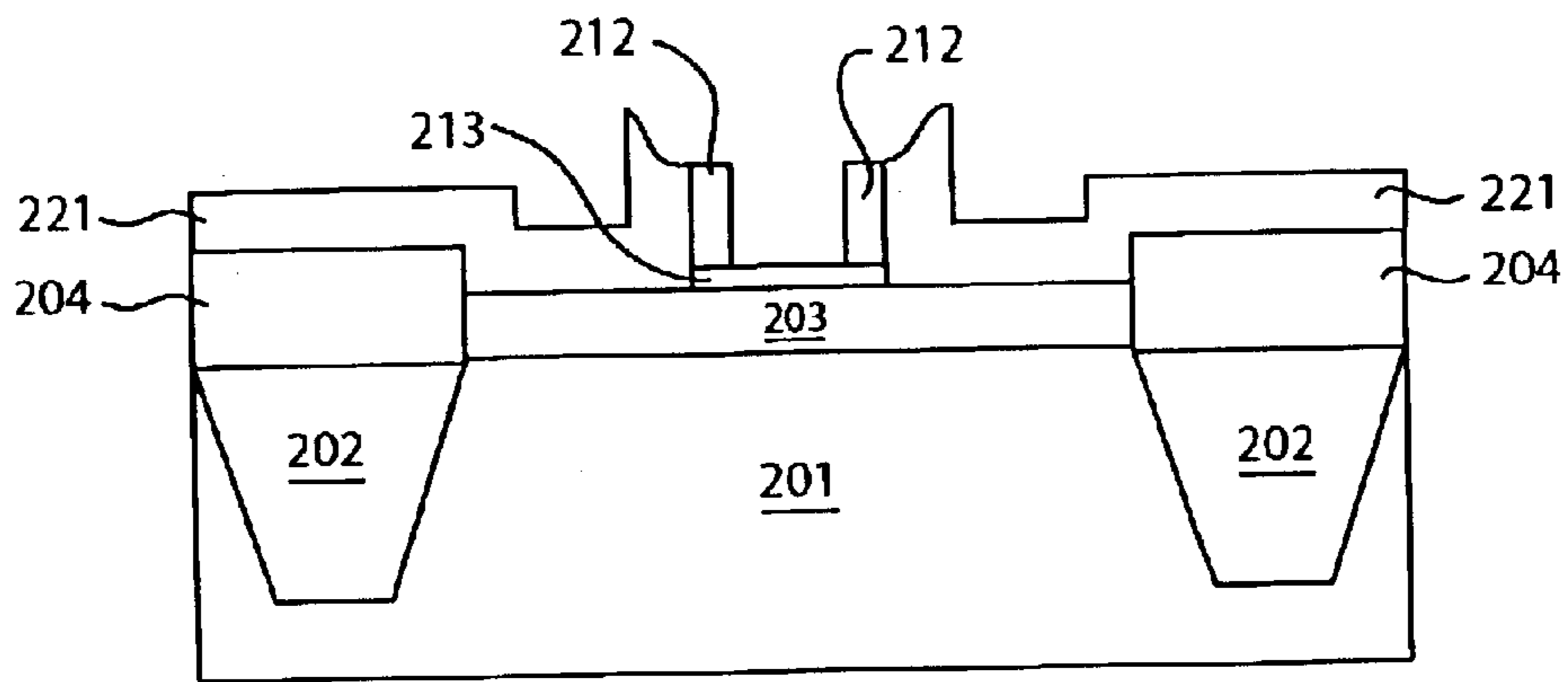


FIG. 2(j)

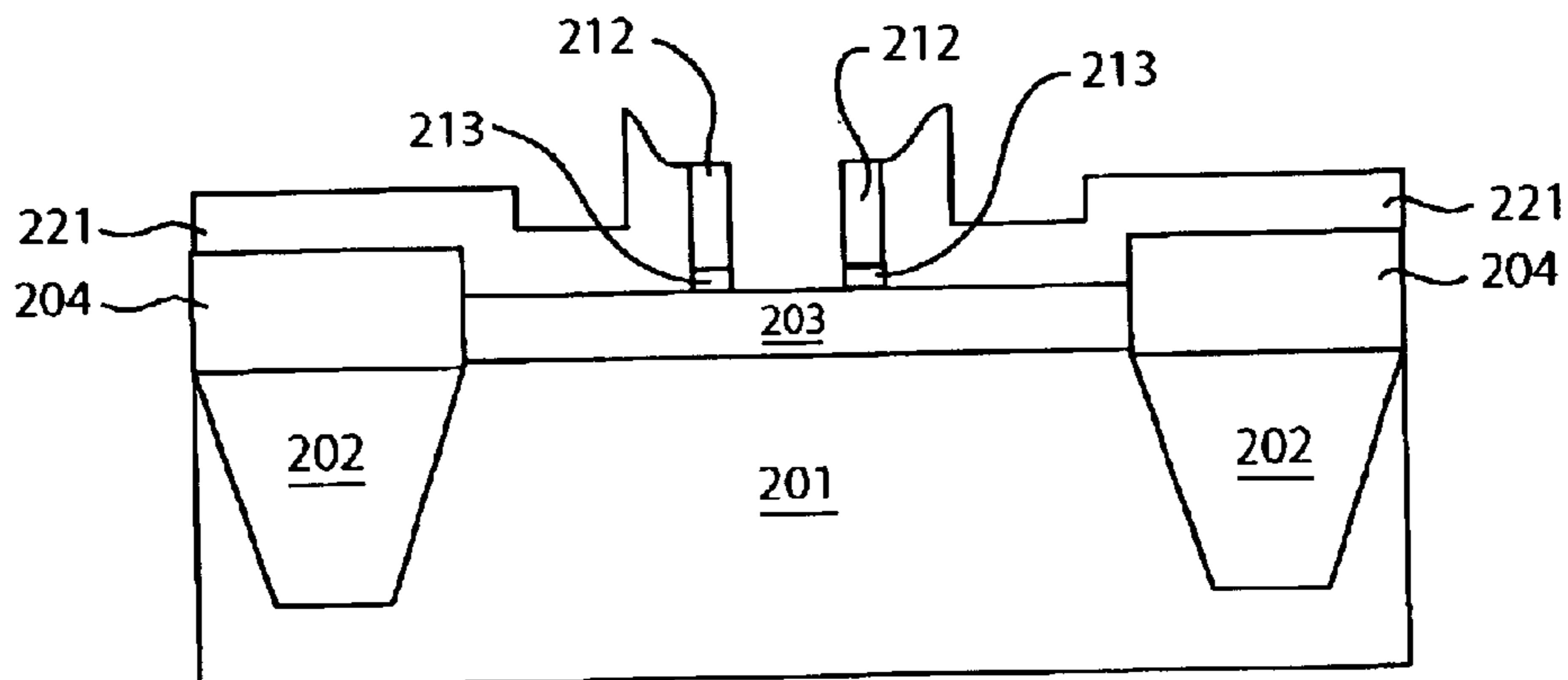


FIG. 2(k)

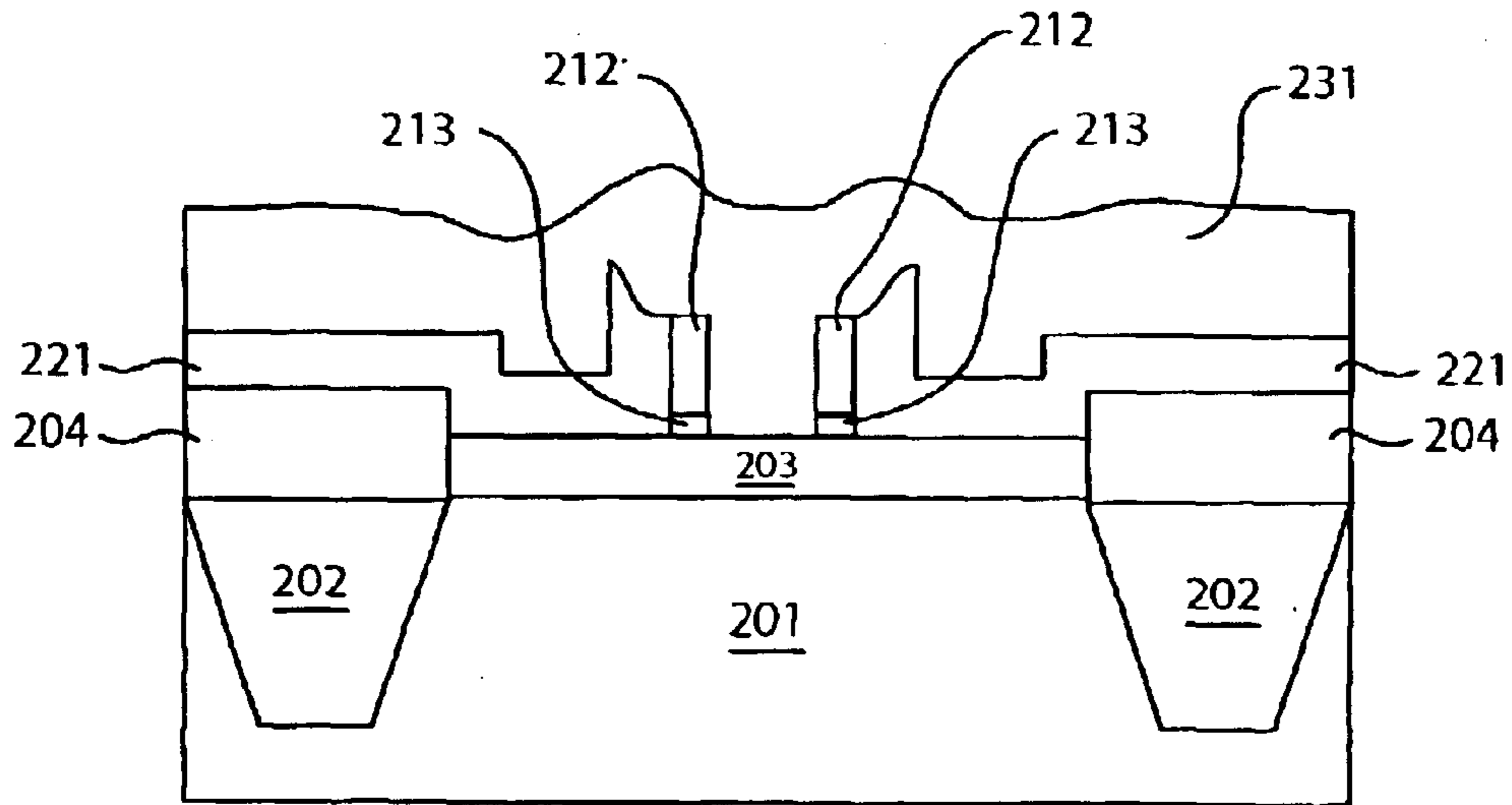


FIG. 2(I)

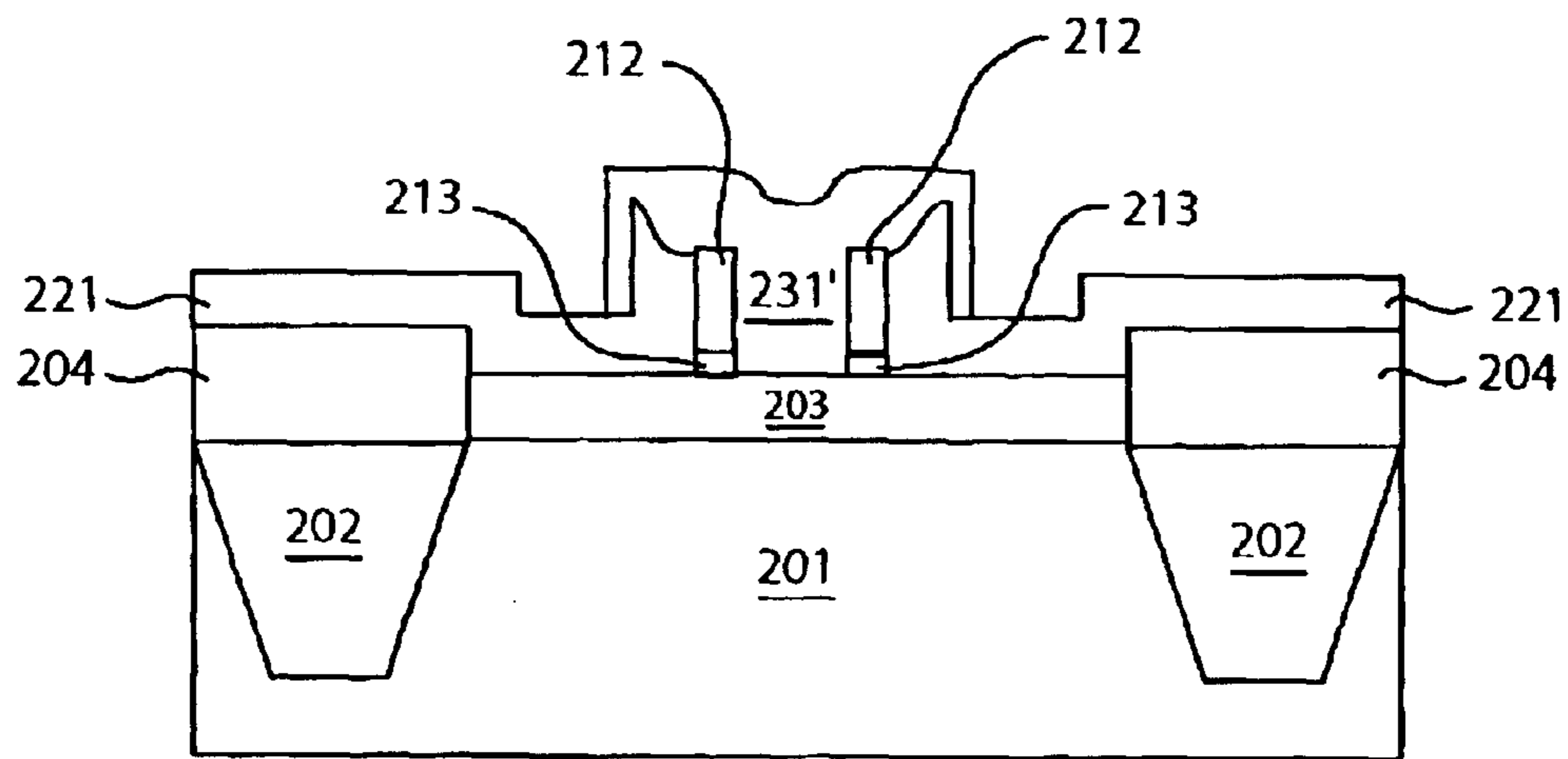


FIG. 2(m)

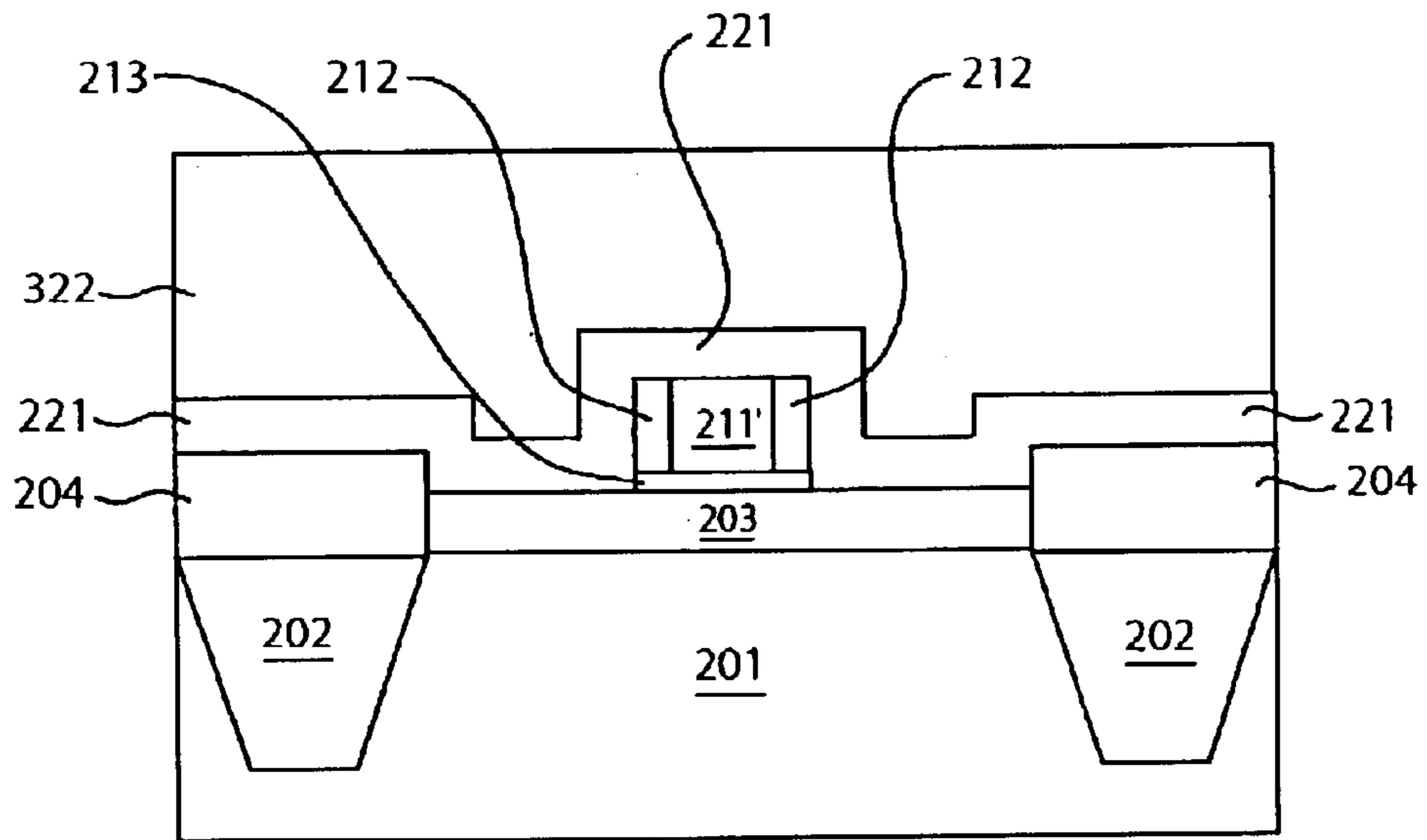


FIG. 3(a)

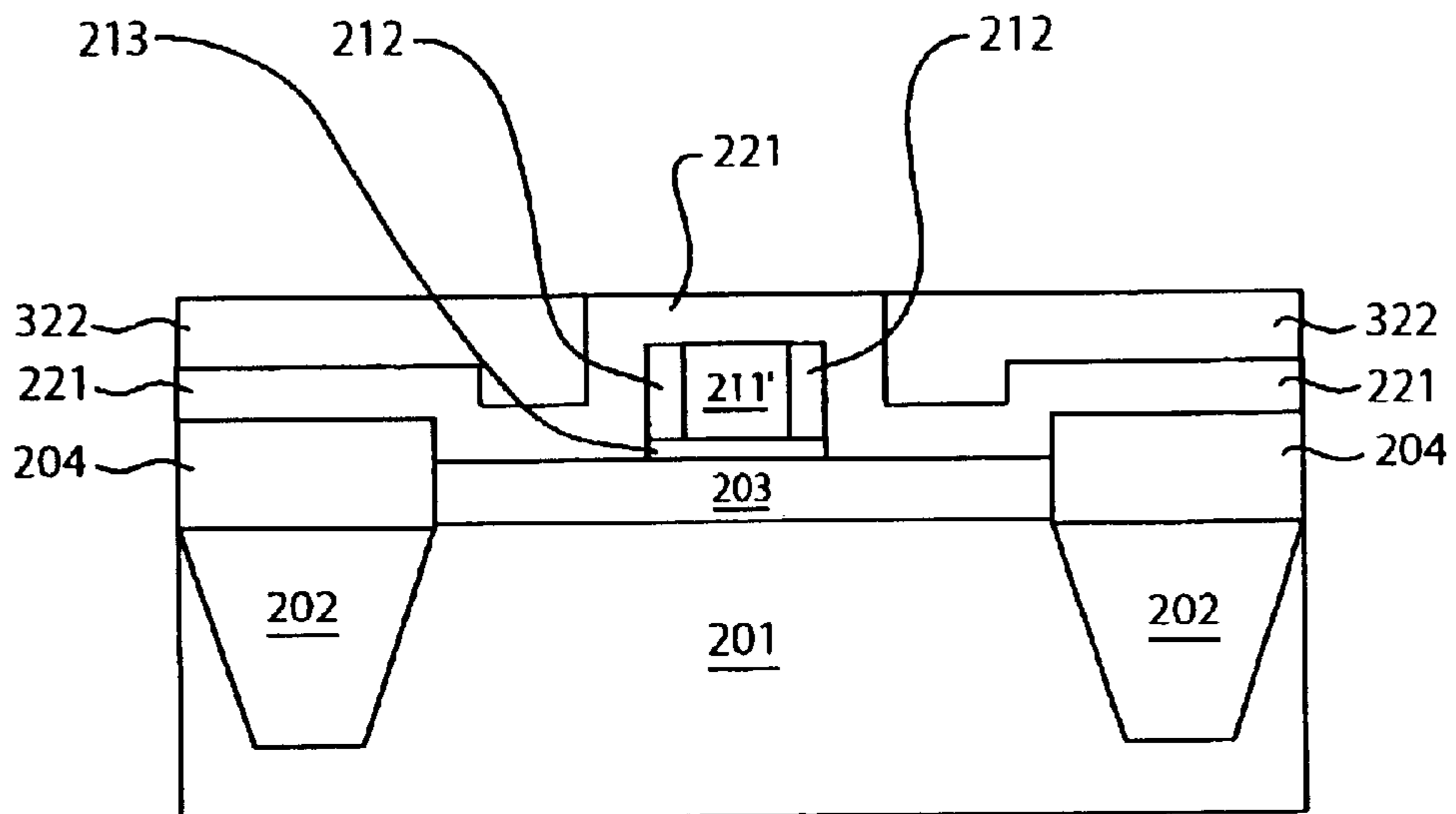


FIG. 3(b)

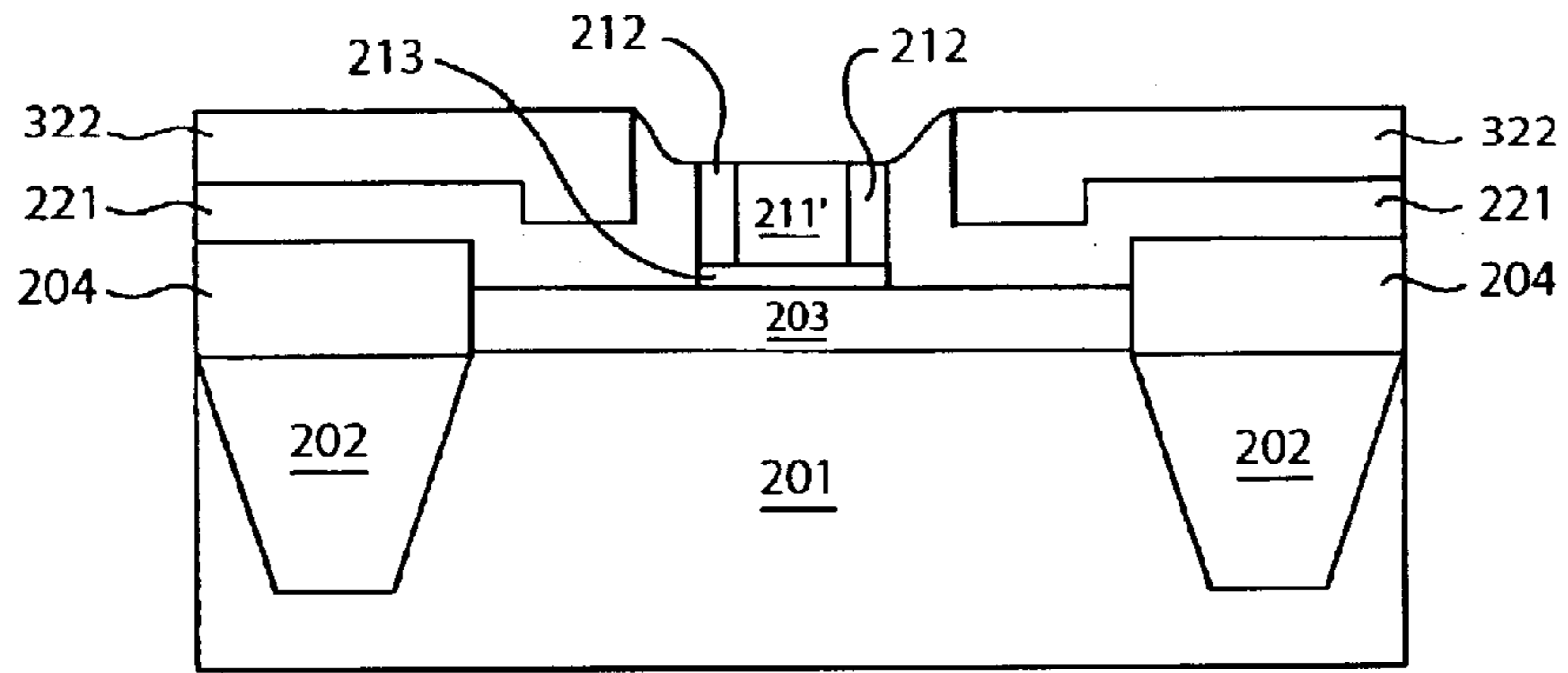


FIG. 3(c)

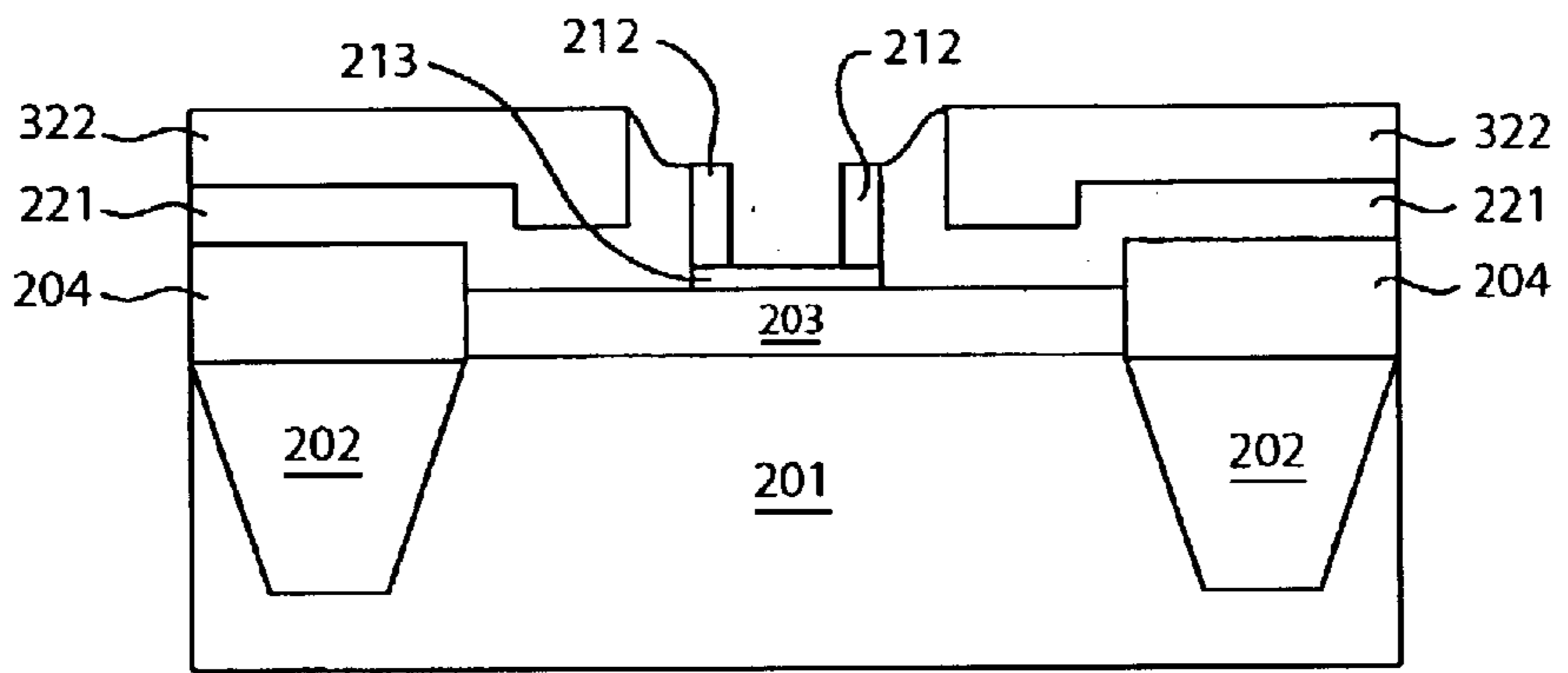


FIG. 3(d)

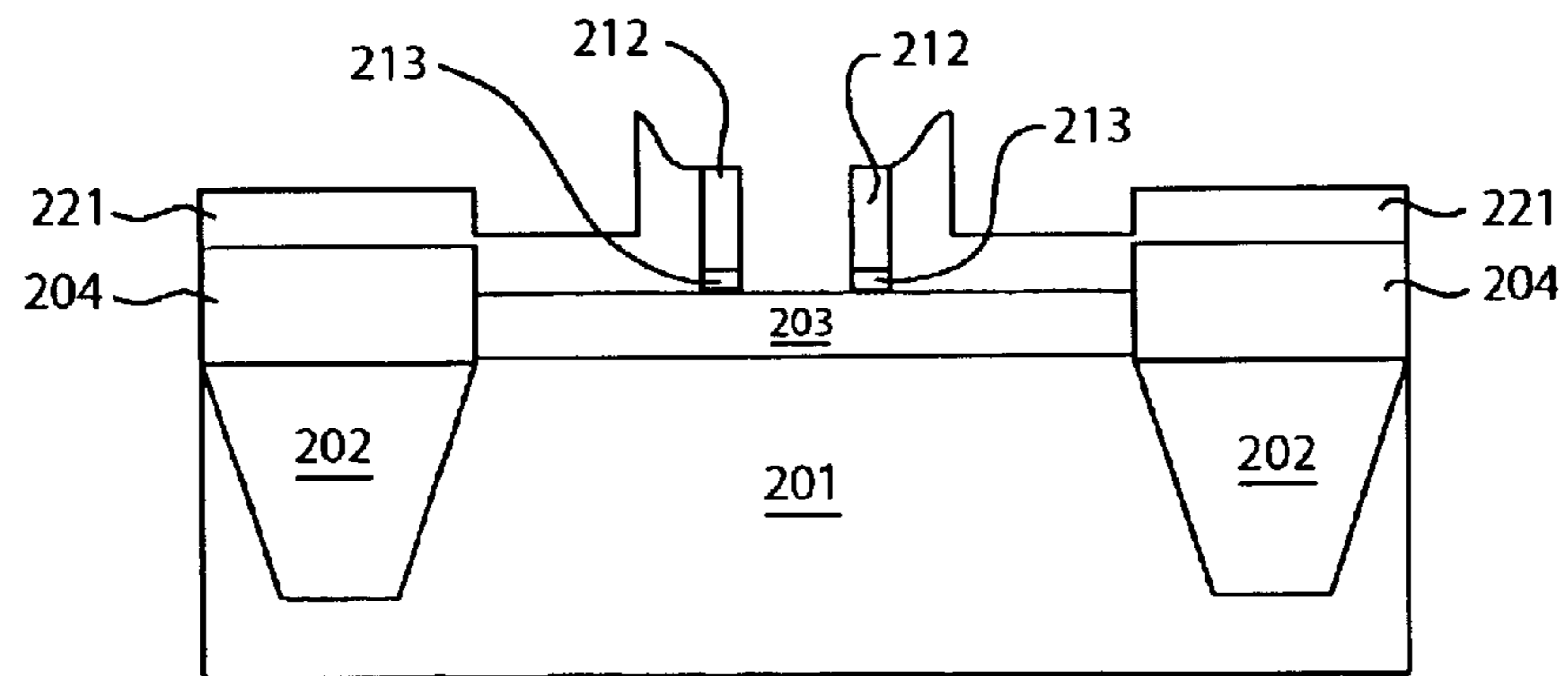


FIG. 3(e)

FABRICATION OF A BIPOLAR TRANSISTOR USING A SACRIFICIAL EMITTER

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to integrated circuits, and more particularly but not exclusively to bipolar transistors.

2. Description of the Background Art

As is well known, a bipolar transistor comprises a base, an emitter, and a collector. In a so-called “SiGe bipolar transistor”, the base comprises silicon-germanium. SiGe bipolar transistors are popular because of their relatively high maximum frequency of oscillation (F_{max}) and switching frequency (F_t), which make them specially suitable for high-frequency applications such as wireless communications.

FIGS. 1(a) to 1(f) show cross-sectional views schematically illustrating a conventional method of forming an SiGe transistor. In FIG. 1(a), an SiGe layer **103** is epitaxially grown on a silicon layer **101**. The epitaxial growth of SiGe layer **103** also results in the growth of polycrystalline silicon-germanium (“poly-SiGe”) layers **104** on isolation structures **102**. Isolation structures **102** may be shallow trench isolation (STI) structures filled with silicon dioxide.

In FIG. 1(b), a polycrystalline silicon (“polysilicon”) layer **106** is formed over a silicon dioxide layer **105**, which is formed over SiGe layer **103** and poly-SiGe layers **104**. A mask comprising photoresists **108** is formed over polysilicon layer **106** to define an emitter window **121** (see FIG. 1(c)).

In FIG. 1(c), emitter window **121** is formed by etching through exposed portions of polysilicon layer **106**, and through silicon dioxide layer **105**. Emitter window **121** exposes a portion of SiGe layer **103** referred to as an “intrinsic base region”. The rest of SiGe layer **103** and poly-SiGe layers **104** are referred to as “extrinsic base regions”. The intrinsic base region serves as the base of the transistor being fabricated.

In FIG. 1(d), a polysilicon layer **107** is deposited over the sample of FIG. 1(c).

In FIG. 1(e), another mask, which comprises a photoresist **109**, is patterned on polysilicon layer **107** to define an emitter.

In FIG. 1(f), polysilicon layer **107** is etched to form the emitter. Extrinsic base implant and activation steps are then performed.

The above described method uses one mask (i.e., photoresists **108**) to define the emitter window and another mask (i.e., photoresist **109**) to define the emitter. A misalignment in any of the two masks may lead to variations in the distance between the emitter and the extrinsic base regions. These distance variations may result in increased capacitance, high base leakage current, and/or high resistance in the base. Additionally, the use of two masks may result in un-implanted regions between the emitter and the extrinsic base regions. These un-implanted regions are high resistance regions that may reduce the F_{max} of the device.

SUMMARY

In one embodiment, a transistor is fabricated by forming a sacrificial emitter over a base, forming an oxide layer over the sacrificial emitter, removing a portion of the oxide layer,

and then removing the sacrificial emitter. An emitter is later formed in the space formerly occupied by the sacrificial emitter. The sacrificial emitter allows a base implant step to be performed early in the process using a single masking step. The base may comprise epitaxial silicon-germanium or silicon.

These and other features of the present invention will be readily apparent to persons of ordinary skill in the art upon reading the entirety of this disclosure, which includes the accompanying drawings and claims.

DESCRIPTION OF THE DRAWINGS

FIGS. 1(a) to 1(f) show cross-sectional views schematically illustrating a conventional method of forming an SiGe transistor.

FIGS. 2(a) to 2(m) show cross-sectional views schematically illustrating a method of fabricating an SiGe transistor in accordance with an embodiment of the present invention.

FIGS. 3(a)–3(e) show cross-sectional views schematically illustrating a method of fabricating an SiGe transistor in accordance with another embodiment of the present invention.

The use of the same reference label in different drawings indicates the same or like components. Drawings are not necessarily to scale unless otherwise noted.

DETAILED DESCRIPTION

In the present disclosure, numerous specific details are provided such as examples of materials, process steps, and structures to provide a thorough understanding of embodiments of the invention. Persons of ordinary skill in the art will recognize, however, that the invention can be practiced without one or more of the specific details. In other instances, wellknown details are not shown or described to avoid obscuring aspects of the invention. For example, masking and implant activation steps not necessary to the understanding of the invention have been omitted in the interest of clarity.

FIGS. 2(a) to 2(m) show cross-sectional views schematically illustrating a method of fabricating an SiGe transistor in accordance with an embodiment of the present invention. In FIG. 2(a), isolation structures **202** are formed in an amorphous silicon layer **201**. Isolation structures **202** may be shallow trench isolation (STI) structures filled with silicon dioxide, for example. Polycrystalline silicon-germanium (“poly-SiGe”) layers **204** and a silicon-germanium (SiGe) layer **203** are formed on isolation structures **202** and silicon layer **201**, respectively. Poly-SiGe layers **204** and epitaxial SiGe layer **203** may be formed by epitaxial growth.

The portion of SiGe layer **203** that will be under a subsequently formed emitter is referred to as an “intrinsic base region”, while the rest of SiGe layer **203** and poly-SiGe layers **204** are referred to as “extrinsic base regions”. The intrinsic base region serves as the base of the transistor being fabricated. Note that although embodiments of the present invention are described using a base comprising SiGe as an example, the present invention may also be employed in the fabrication of transistors having a base comprising silicon. That is, layer **203** may be a silicon layer instead of an SiGe layer.

In FIG. 2(b), an oxide layer **213** is formed over the sample of FIG. 2(a). Oxide layer **213** may comprise silicon dioxide deposited using TEOS as a precursor. In one embodiment, oxide layer **213** is deposited to a thickness of about 300

Angstroms by plasma enhanced chemical vapor deposition (PECVD). Thereafter, a polycrystalline silicon (“polysilicon”) layer **211** is formed over oxide layer **213**. Polysilicon layer **211** may be deposited to a thickness of about 2500 Angstroms by low-pressure chemical vapor deposition (LPCVD), for example. Polysilicon layer **211** serves as a sacrificial emitter material, and therefore does not need implantation and activation steps.

It is to be noted that as used in the present disclosure, the terms “over”, “overlying”, “under” and “underlying” refer to the relative placement of two materials that may or may not be directly in contact with each other. That is, the two materials may be separated by another material. For example, another material may be placed between polysilicon layer **211** and oxide layer **213**.

Also shown in FIG. 2(b) is a mask (sacrificial emitter mask) comprising photoresist **241**. Photoresist **241** defines the sacrificial emitter **211'** (see FIG. 2(c)).

In FIG. 2(c), polysilicon layer **211** is etched to form sacrificial emitter **211'**. Sacrificial emitter **211'** may be formed by dry etching polysilicon layer **211**. Sacrificial emitter **211'** may have a width of about 0.13 microns to about 0.5 microns depending on the application. As will be more apparent below, sacrificial emitter **211'** is used to self-align a base implantation step. Sacrificial emitter **211'** is removed at a later step to make room for an emitter.

In FIG. 2(d), spacers **212** are formed on the sidewalls of sacrificial emitter **211'**.

In one embodiment, spacers **212** are formed by depositing a silicon nitride layer over the sample of FIG. 2(c), and then blanket etching the silicon nitride layer. Blanket etching allows spacers **212** to be formed with relatively good accuracy, which in turn allows for additional margin of error in forming sacrificial emitter **211'**. Spacers **212** may be formed to a width of about 700 Angstroms, for example.

Preferably, spacers **212** are “boxy” in that they have substantially vertical sidewalls. One way of forming boxy spacers **212** is to etch a silicon nitride spacer material in a two step dry etch process having: (a) a first step employing an etch chemistry comprising C_2F_6 , Ar, and O_2 , and (b) a second step employing an etch chemistry comprising CF_4 and O_2 . The first step is also referred to as a “main etch”, and may be terminated using an end-point detector. The second step may be a timed etch.

In FIG. 2(e), portions of oxide layer **213** not under sacrificial emitter **211'** are removed using a wet-etch process. Thereafter, an extrinsic base implant step is performed. In one embodiment, the dopant implanted in the extrinsic base regions is a P-type dopant, such as Boron or BF_2 , to form an NPN SiGe transistor. The dopant is then activated in a later step not shown.

As can be appreciated from the foregoing, the base implant step is self-aligned with respect to spacers **212**, which is formed with respect to sacrificial emitter **211'**. Because sacrificial emitter **211'** is formed using a single mask (i.e., photoresist **241**), problems associated with variations in the distance between the extrinsic base regions and a subsequently formed emitter (see emitter **231'** shown in FIG. 2(m)) are alleviated.

In FIG. 2(f), an oxide layer **221** is formed over the sample of FIG. 2(e). As will be more apparent below, oxide layer **221** advantageously facilitates removal of sacrificial emitter **211'** by covering materials that need to be protected during etching steps. Oxide layer **221** may comprise silicon dioxide deposited using TEOS as a precursor. Oxide layer **221** may be deposited to a thickness of about 1000 Angstroms by

low-temperature low-pressure chemical vapor deposition (LPCVD). Preferably, oxide layer **221** is conformally deposited (i.e., with substantially uniform thickness throughout) to have enough material for subsequent etching steps. For example, oxide layer **221** and a spacer **212** preferably has a total width **223** that is greater than 2 lynch. As is well known, a “lynch” is a minimum error margin for two layers of materials that are to be aligned. The value of a lynch depends on application specific factors, such as critical dimensions and the stepper used for alignment.

In FIG. 2(g), a mask comprising photoresists **222** is formed over the sample of FIG. 2(f) such that a portion of oxide layer **221** over sacrificial emitter **211'** is exposed. In one embodiment, photoresists **222** are formed by spin coating a photoresist material over the sample of FIG. 2(f), and then performing alignment, exposure, and development steps such that a hole through the photoresist material is in-line with sacrificial emitter **211'**. Photoresists **222** may be formed to a thickness of about 5000 Angstroms to about 1.5 microns, depending on the application. Photoresists **222** may have an underlying anti-reflective coating. In that case, the anti-reflective coating may have to be etched to expose oxide layer **221**. Preferably, a developable anti-reflective coating is employed so that it can be developed at the same time as photoresists **222**, thus obviating the need to remove the anti-reflective coating in a separate etching step.

In FIG. 2(h), a portion of oxide layer **221** is removed to expose sacrificial emitter **211'**. In one embodiment, the portion of oxide layer **221** is removed using a wet etch process, such as a BOE (buffered oxide etch) process. A wet etch process is isotropic and thus results in an undercut under photoresists **222**. The undercut helps in completely exposing the top portion of sacrificial emitter **211'**. This, in turn, advantageously facilitates removal of sacrificial emitter **211'** in a subsequent etching step.

In FIG. 2(i), photoresists **222** are removed from the sample of FIG. 2(h). Note that depending on the application, photoresists **222** may also be removed in a later step.

In FIG. 2(j), sacrificial emitter **211'** is removed. In one embodiment, sacrificial emitter **211'** is removed using a poly-etch process that is selective to spacers **212** of silicon nitride and oxide layers **221** and **213**. For example, sacrificial emitter **211'** may be dry etched using an etch chemistry comprising HBr, Cl_2 , and He. Sacrificial emitter **211'** may be etched using oxide layer **213** as an etch stop.

In FIG. 2(k), a portion of oxide layer **213** is removed to expose SiGe layer **203**. In one embodiment, the portion of oxide layer **213** is removed using a wet etch process referred to as a “pre-clean”. Etching of oxide layer **213** allows an emitter (e.g., emitter **231'** shown in FIG. 2(m)) to make contact with the intrinsic base comprising SiGe layer **203**.

In FIG. 2(l), an emitter material comprising a polysilicon layer **231** is formed over the sample of FIG. 2(k). Polysilicon layer **231** may be formed to a thickness of about 1500 Angstroms to about 2500 Angstroms by LPCVD. A dopant is then implanted and later activated in polysilicon layer **231**. In one embodiment, an N-type dopant, such as Arsenic, is implanted and activated in polysilicon layer **231** to form an NPN SiGe transistor. Depending on the application, the emitter material may also be an in-situ doped non-selective epitaxial layer or polysilicon layer, or an in-situ doped selective epitaxial layer.

In FIG. 2(m), polysilicon layer **231** is etched to form an emitter **231'**.

As can be appreciated from the foregoing, sacrificial emitter **211'** advantageously allows a self-aligned base

implant step to be performed relatively early in the fabrication process. After the base implant step, sacrificial emitter **211'** is removed to allow an emitter to be formed in its place. The just described method of fabricating an SiGe transistor illustrates one way of removing sacrificial emitter **211'**. Another way of removing sacrificial emitter **211'** is now described with reference to FIGS. **3(a)–3(e)**.

FIGS. **3(a)–3(e)** show cross-sectional views schematically illustrating a method of fabricating an SiGe transistor in accordance with another embodiment of the present invention. In FIG. **3(a)**, a mask comprising photoresist **322** is formed over the sample of FIG. **2(f)**. That is, photoresist **322** is formed after the process steps illustrated with reference to FIGS. **2(a)–2(f)** are completed. In one embodiment, photoresist **322** is formed to a thickness of about 7000 Angstroms by spin coating.

In FIG. **3(b)**, photoresist **322** is planarized to expose a portion of oxide layer **221** over sacrificial emitter **211'**. In one embodiment, photoresist **322** is planarized using an etch-back process that is selective to oxide layer **221**. For example, an etch chemistry comprising Cl_2 may be used to achieve a selectivity of approximately 10:1 to 15:1 with respect to oxide layer **221**. Portions of photoresist **322** that were not etched serve as a mask for subsequent etching steps. For any given application, the thickness of photoresist **322** may be increased to improve the etch-back error margin.

In FIG. **3(c)**, a portion of oxide layer **221** is removed to expose sacrificial emitter **211'**. In one embodiment, the portion of oxide layer **211** is removed by performing a wet etch process, such as a BOE process, on the sample of FIG. **3(b)**. The wet etch process isotropically etches oxide layer **211** to advantageously expose most of the top portion of sacrificial emitter **211'**.

In FIG. **3(d)**, sacrificial emitter **211'** is removed. In one embodiment, sacrificial emitter **211'** is removed using a poly-etch process that is selective to spacers **212** of silicon nitride and oxide layers **221** and **213**. For example, sacrificial emitter **211'** may be dry etched using an etch chemistry comprising HBr, Cl_2 , and He. Sacrificial emitter **211'** may also be wet etched using an etch chemistry comprising XeF_2 or $\text{HNO}_3:\text{HF}$ mixture. Sacrificial emitter **211'** may be etched using oxide layer **213** as an etch stop.

In FIG. **3(e)**, a portion of oxide layer **213** is removed to expose SiGe layer **203**. In one embodiment, the portion of oxide layer **213** is removed using a wet etch process referred to as a “pre-clean”. Etching of oxide layer **213** allows an emitter (e.g., emitter **231'** shown in FIG. **2(m)**) to make contact with the intrinsic base comprising SiGe layer **203**. Also in FIG. **3(e)**, remaining portions of photoresist **322** are removed. Depending on the application, photoresist **322** may also be removed at anytime after the etching of oxide layer **221**.

Thereafter, an emitter may be formed in place of sacrificial emitter **211'** as in FIGS. **2(l)** and **2(m)**.

While specific embodiments of the present invention have been provided, it is to be understood that these embodiments are for illustration purposes and not limiting. Many additional embodiments will be apparent to persons of ordinary skill in the art reading this disclosure. For example, although the above embodiments illustrate the fabrication of an NPN SiGe transistor, embodiments of the invention may also be adapted to fabricate PNP SiGe transistors. Thus, the invention is limited only by the following claims.

What is claimed is:

1. A method of fabricating a bipolar transistor, the method comprising:

forming a sacrificial emitter over a base;
forming a first oxide layer over the sacrificial emitter;
forming a masking material over the first oxide layer;
planarizing the masking material to expose the first oxide layer;
etching a portion of the first oxide layer over the sacrificial emitter; and
removing the sacrificial emitter.

2. The method of claim **1** wherein the base comprises silicon-germanium (SiGe).

3. The method of claim **1** wherein the sacrificial emitter comprises:

a polysilicon material over a second oxide layer.

4. The method of claim **1** further comprising:

after forming the sacrificial emitter but prior to forming the first oxide layer, implanting a dopant in an extrinsic base region.

5. The method of claim **1** wherein the base comprises silicon.

6. The method of claim **1** wherein removing the sacrificial emitter comprises:

etching the sacrificial emitter using a second oxide layer as an etch stop; and

etching the second oxide layer to expose the base.

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

forming a polysilicon material on the base.

8. The method of claim **1** wherein forming the masking material over the first oxide layer comprises spin-coating a photoresist material.

9. The method of claim **1** wherein planarizing the masking material comprises performing an etch-back process.

10. A method of forming a bipolar transistor, the method comprising:

implanting a dopant in a silicon-germanium (SiGe) layer that is under a sacrificial emitter;

depositing a first oxide layer over the sacrificial emitter;
forming a mask over the first oxide layer:

isotropically etching the first oxide layer to create an undercut under the mask and fully expose a top portion of the sacrificial emitter; and

replacing the sacrificial emitter with an emitter.

11. The method of claim **10** wherein replacing the sacrificial emitter with an emitter comprises:

etching the sacrificial emitter to expose a second oxide layer;

etching the second oxide layer to expose the SiGe layer; and

forming the emitter in a volume previously occupied by the sacrificial emitter.

12. The method of claim **1** wherein the masking material comprises photoresist.

13. A method of fabricating a bipolar transistor, the method comprising:

forming a sacrificial emitter over a base;

forming a first oxide layer over the sacrificial emitter;

forming a masking material over the sacrificial emitter such that a portion of the first oxide layer is exposed;

isotropically etching the first oxide layer to create an undercut under the masking material and fully expose a top portion of the sacrificial emitter; and

removing the sacrificial emitter.

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14. The method of claim **13** wherein isotropically etching the first oxide layer comprises wet etching the first oxide layer.

15. The method of claim **13** wherein the base comprises silicon-germanium (SiGe).

16. The method of claim **13** wherein the sacrificial emitter comprises:

a polysilicon material over a second oxide layer.

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17. The method of claim **13** further comprising:
after forming the sacrificial emitter but prior to forming the first oxide layer, implanting a dopant in an extrinsic base region.

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