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(54) **SELF-ALIGNMENT OF MICRO LIGHT
EMITTING DIODE USING PLANARIZATION**

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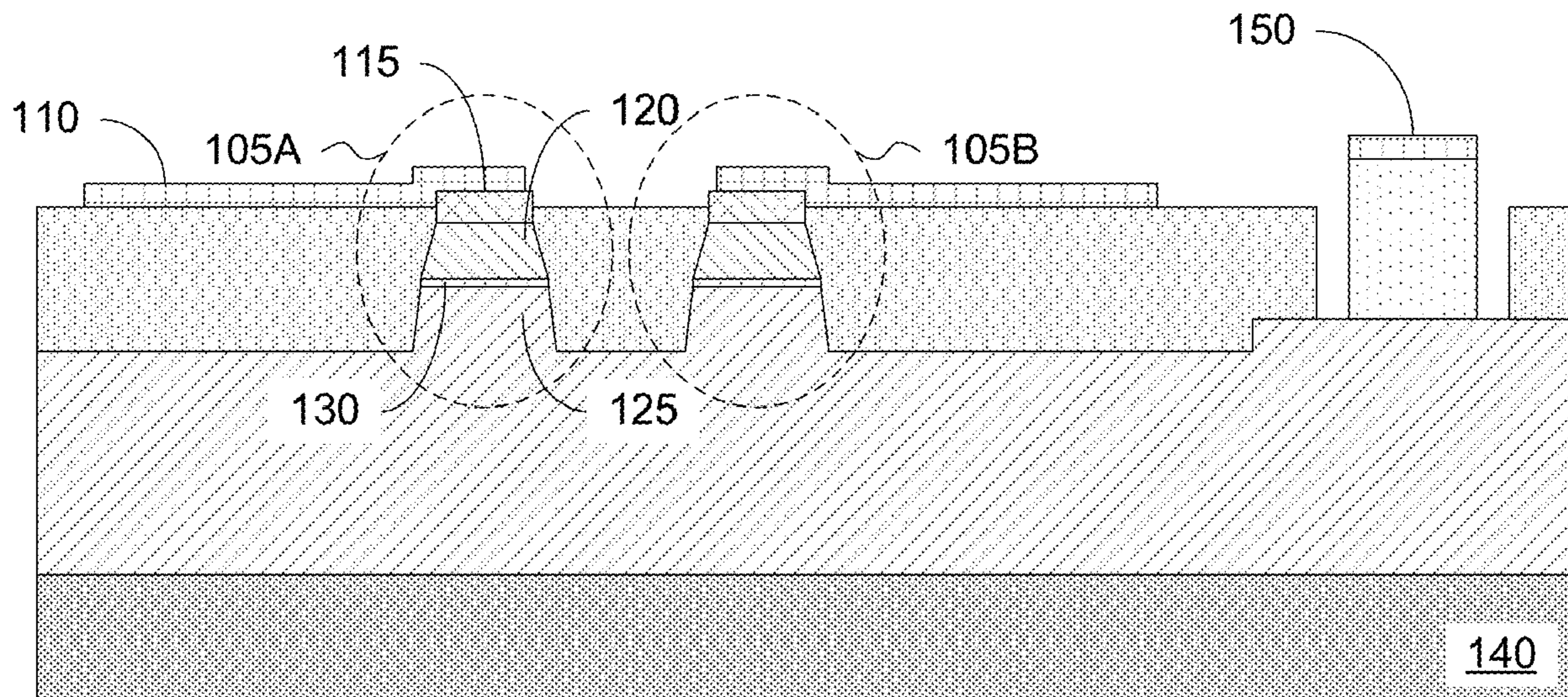
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(63) Continuation of application No. 16/801,118, filed on
Feb. 25, 2020, now Pat. No. 11,302,841, which is a
continuation of application No. 15/958,316, filed on
Apr. 20, 2018, now Pat. No. 10,615,305.

(57) **ABSTRACT**

Embodiments relate to a method for fabricating a light-emitting-diode (LED). A metal layer is deposited on a p-type semiconductor. The p-type semiconductor is on an n-type semiconductor. The metal layer is patterned to define a p-metal. The p-type semiconductor is etched using the p-metal as an etch mask. Similarly, the n-type semiconductor is etched using the p-metal and the p-type semiconductor as an etch mask to define individual LEDs.



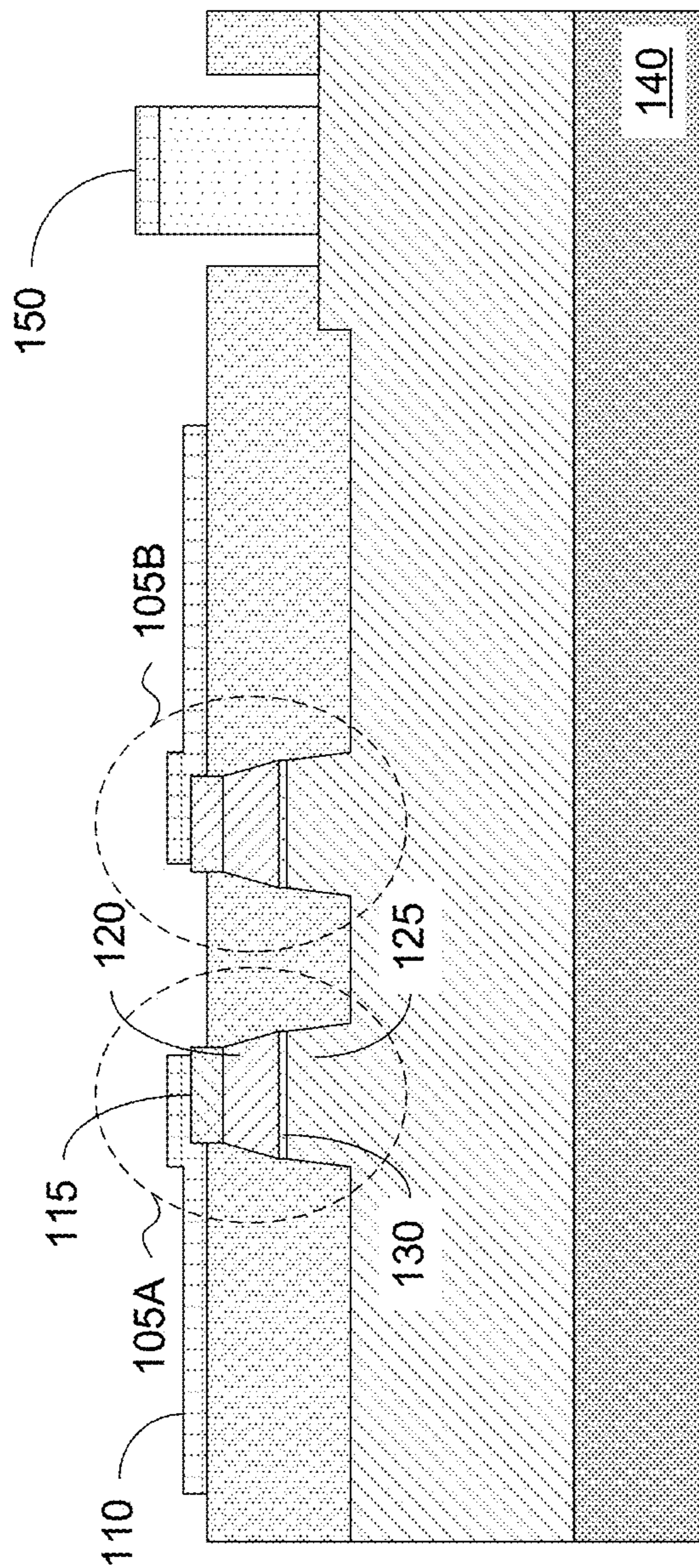
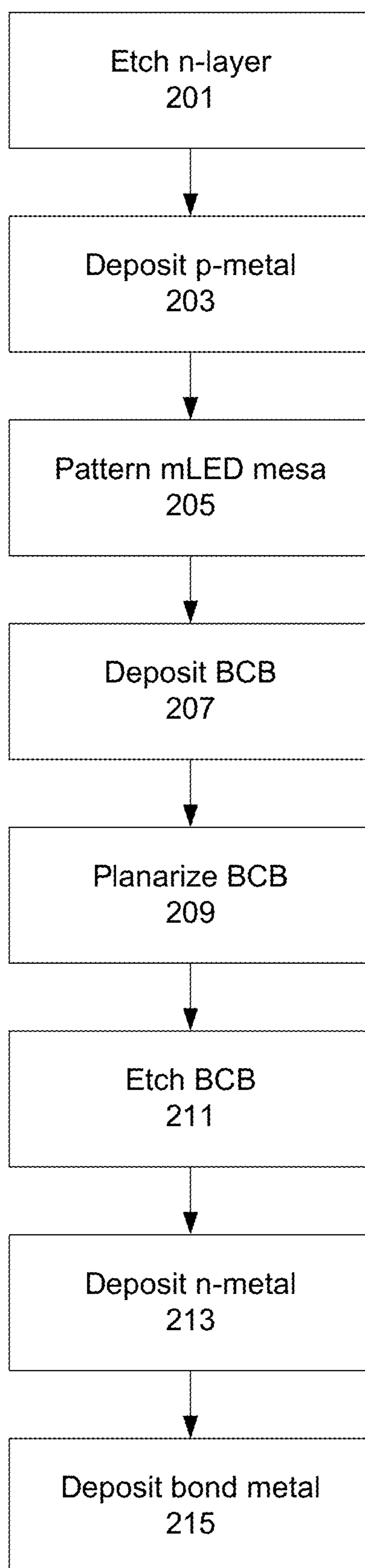


FIG. 1

**FIG. 2**

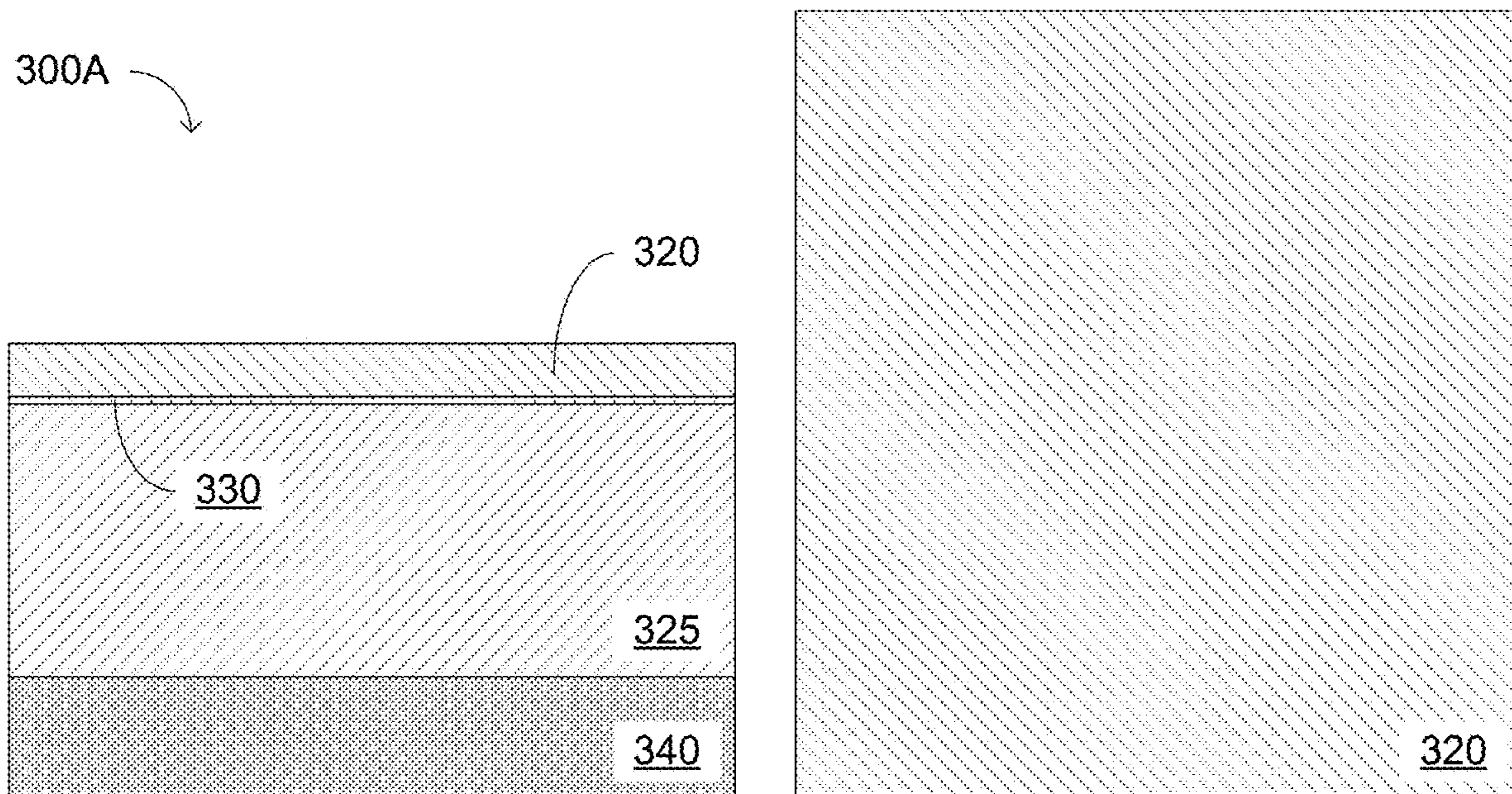


FIG. 3A

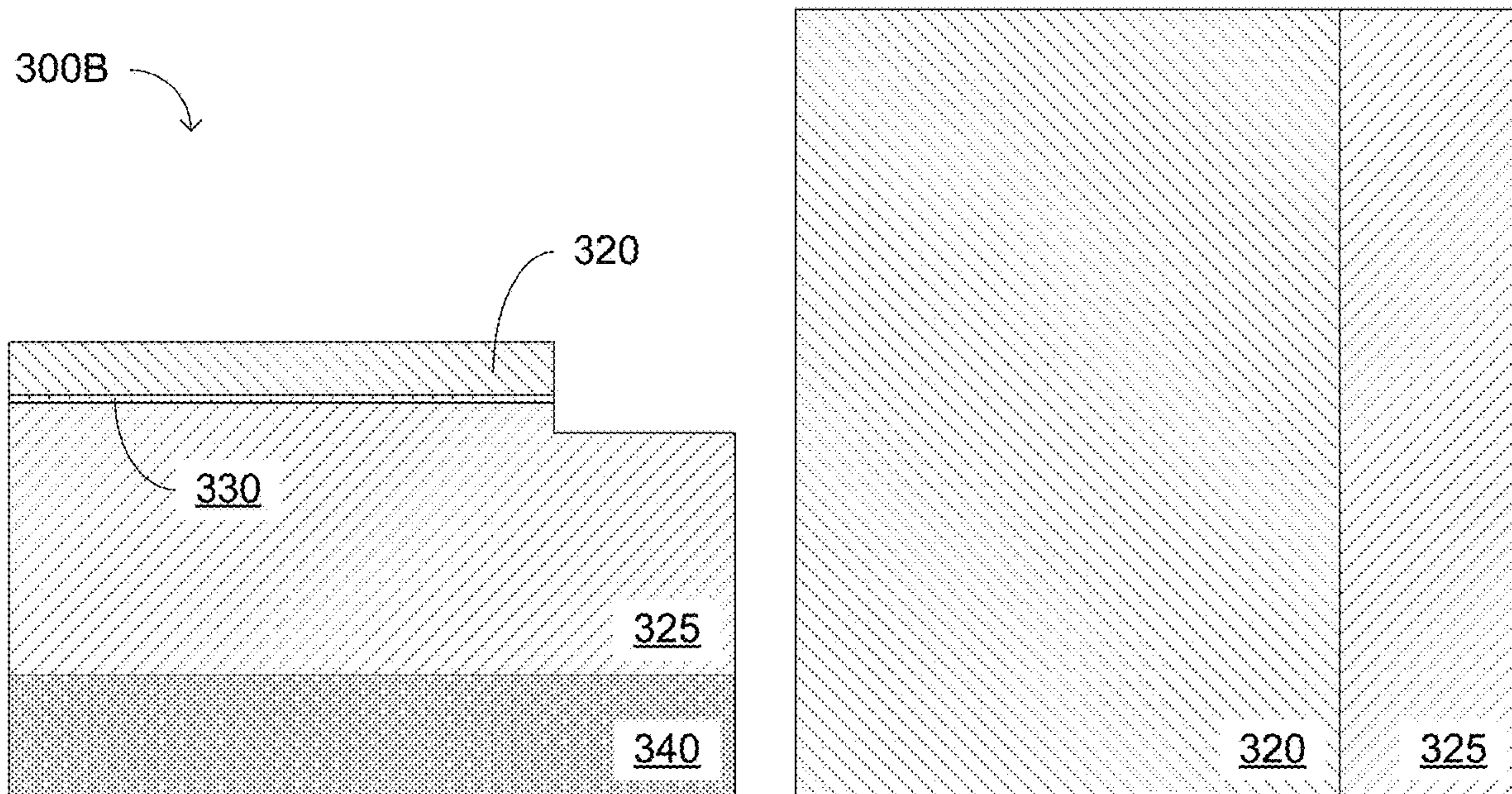


FIG. 3B

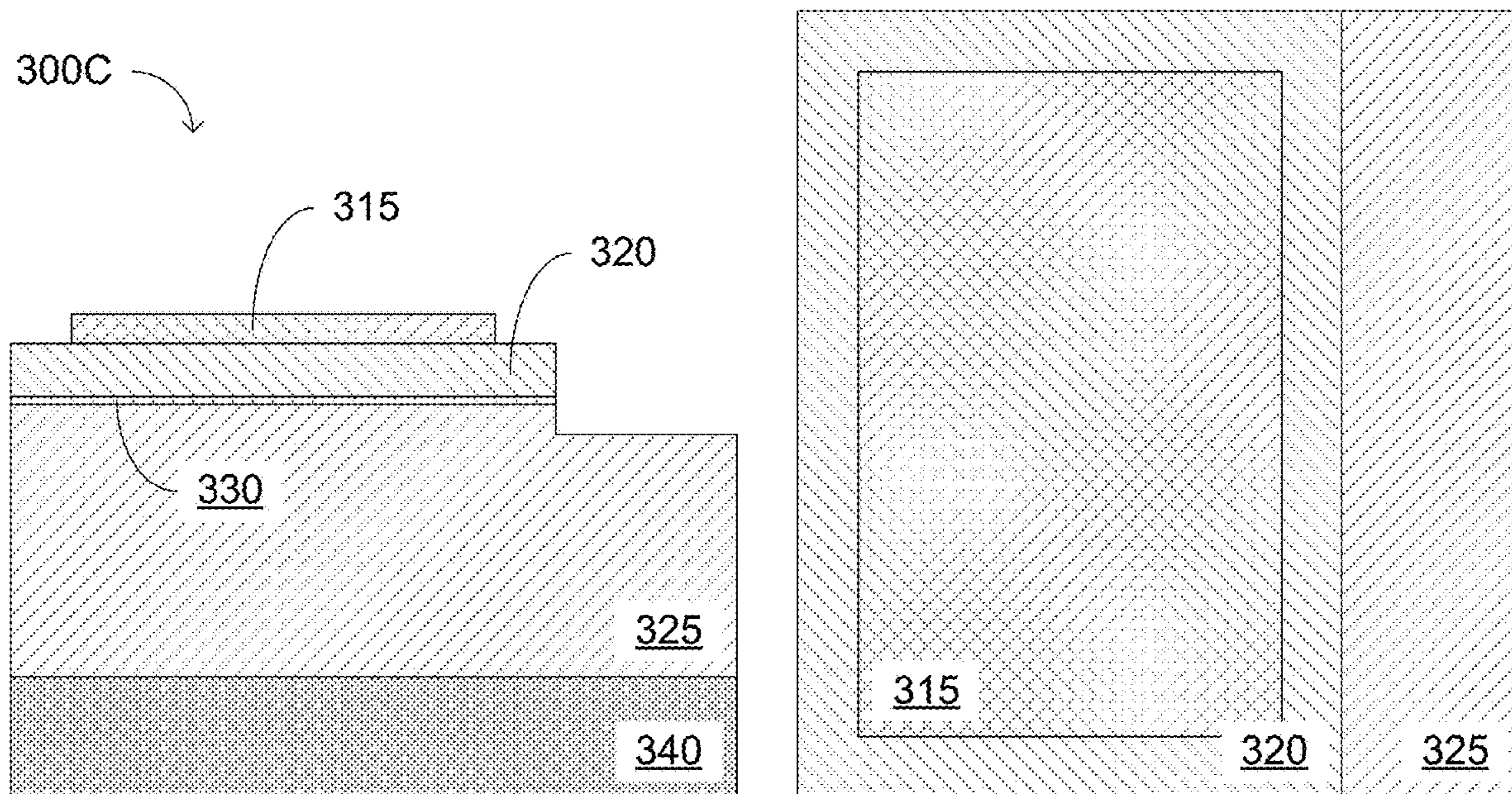


FIG. 3C

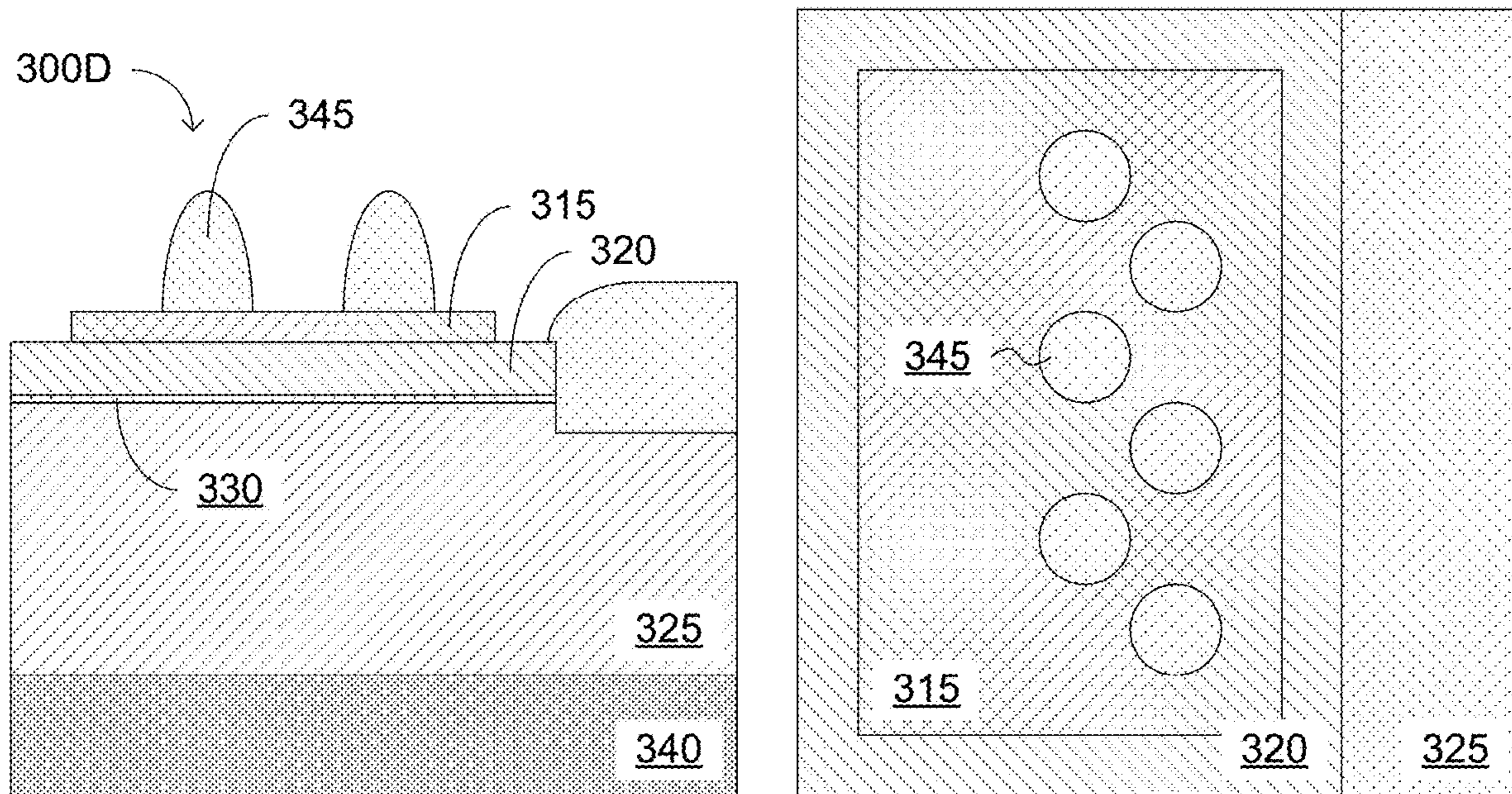


FIG. 3D

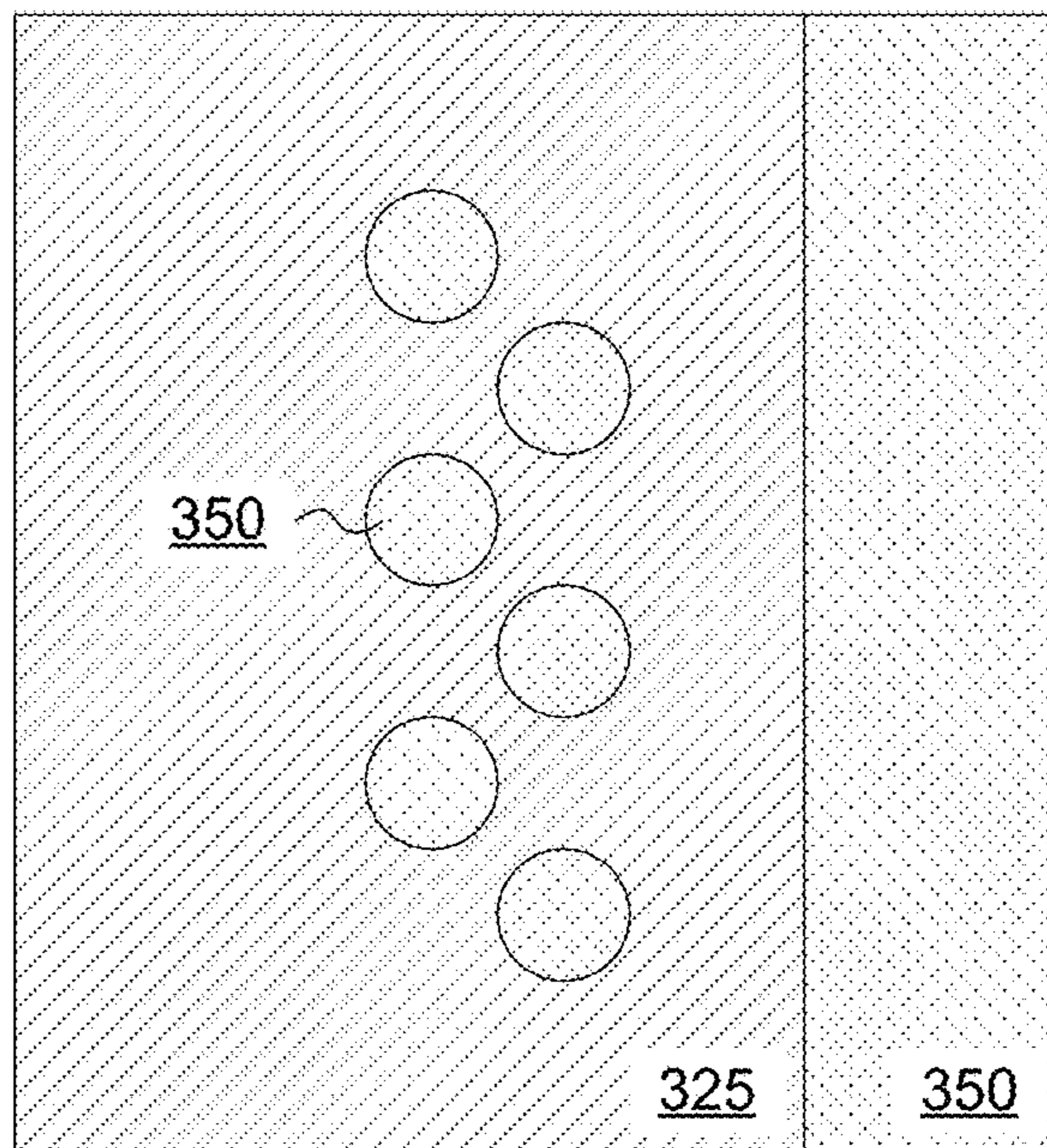
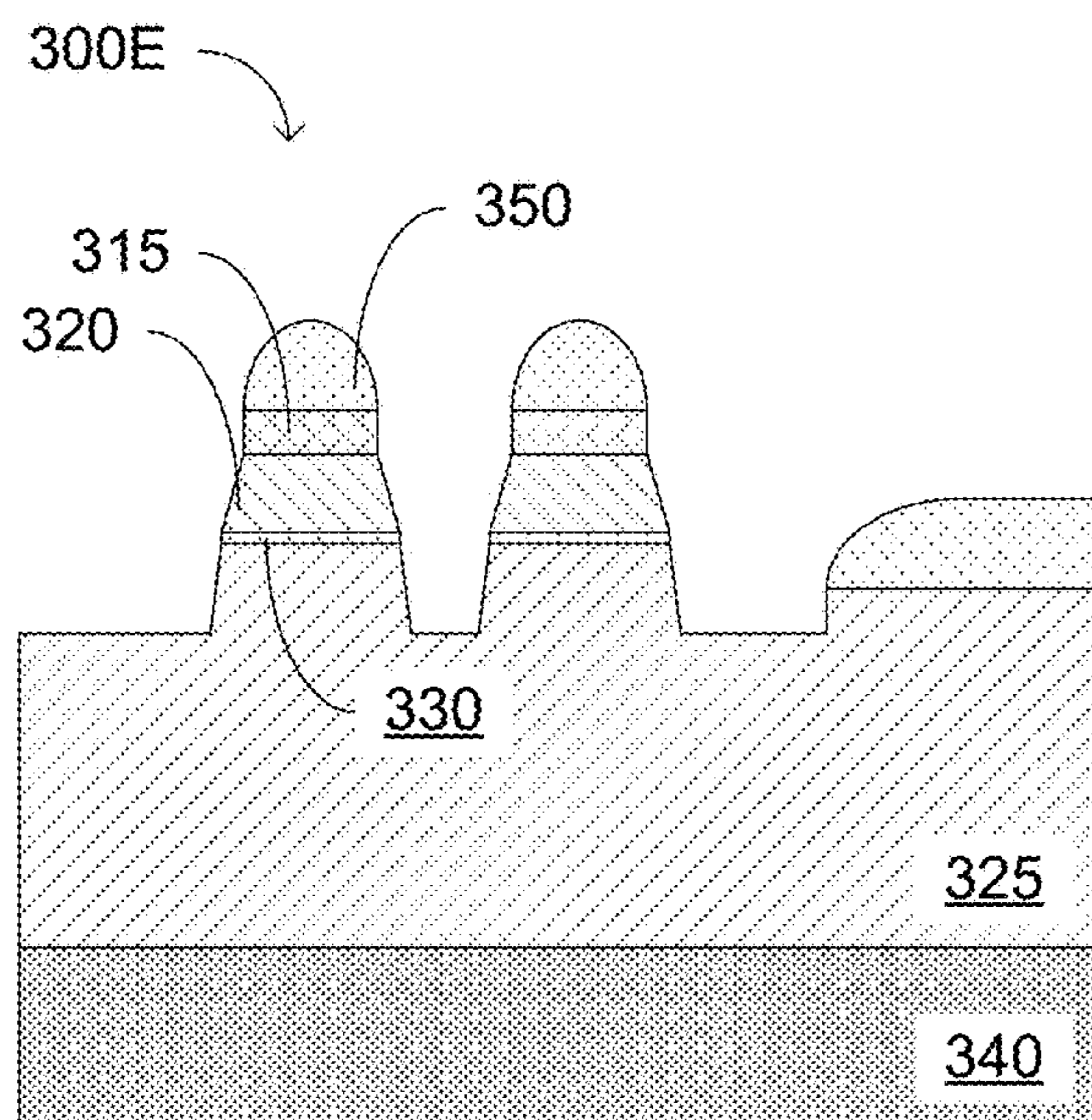


FIG. 3E

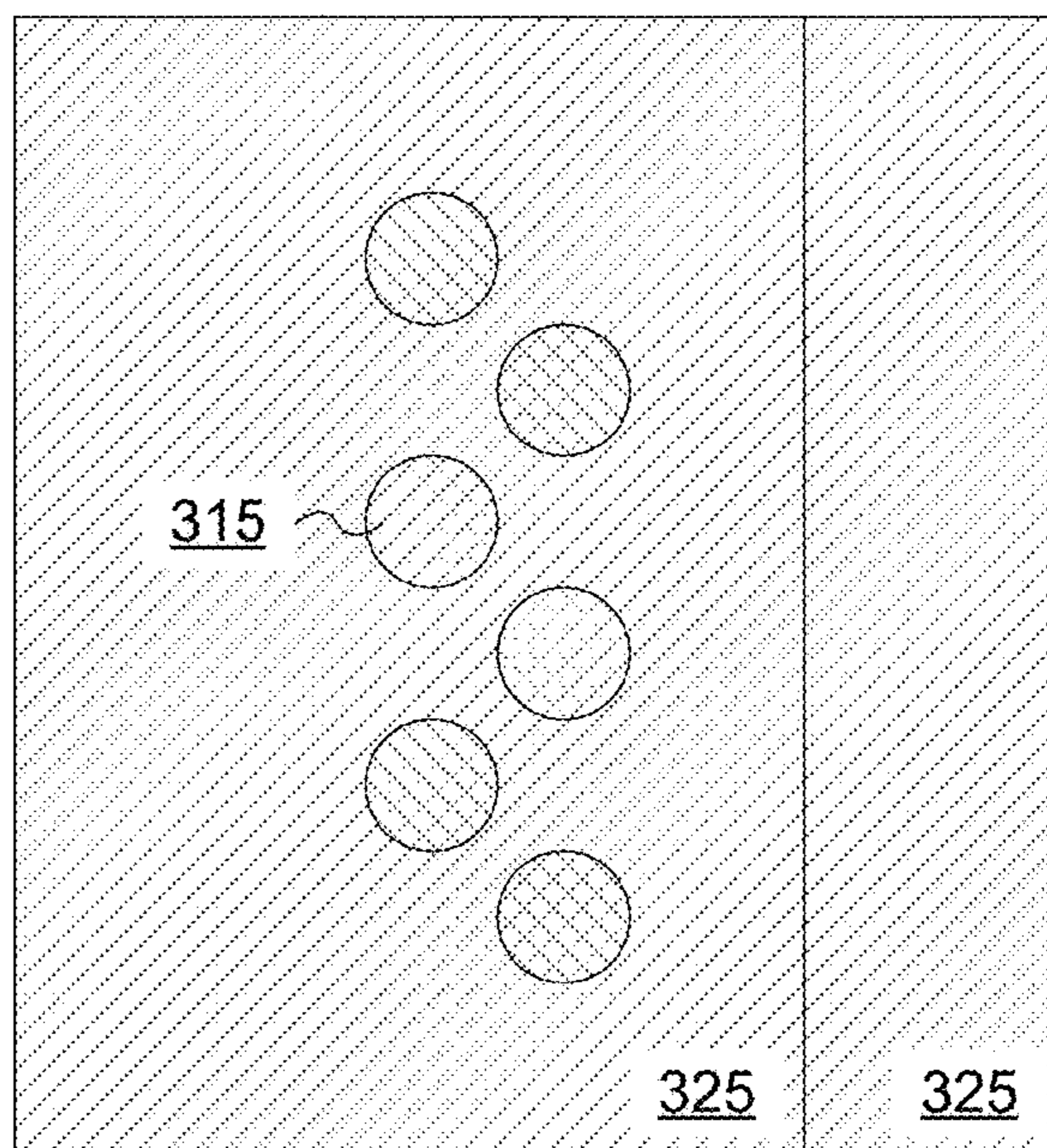
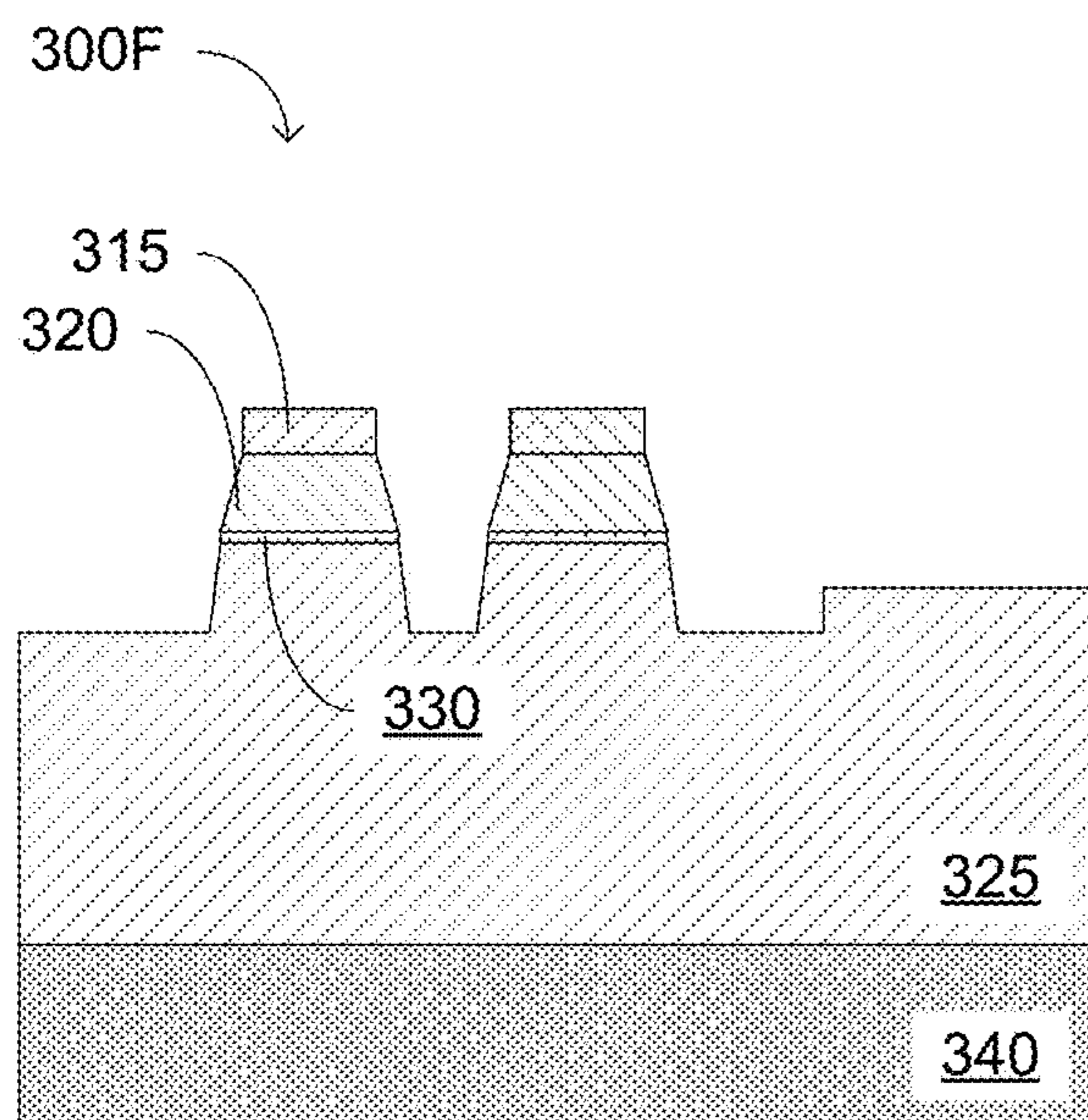


FIG. 3F

300G

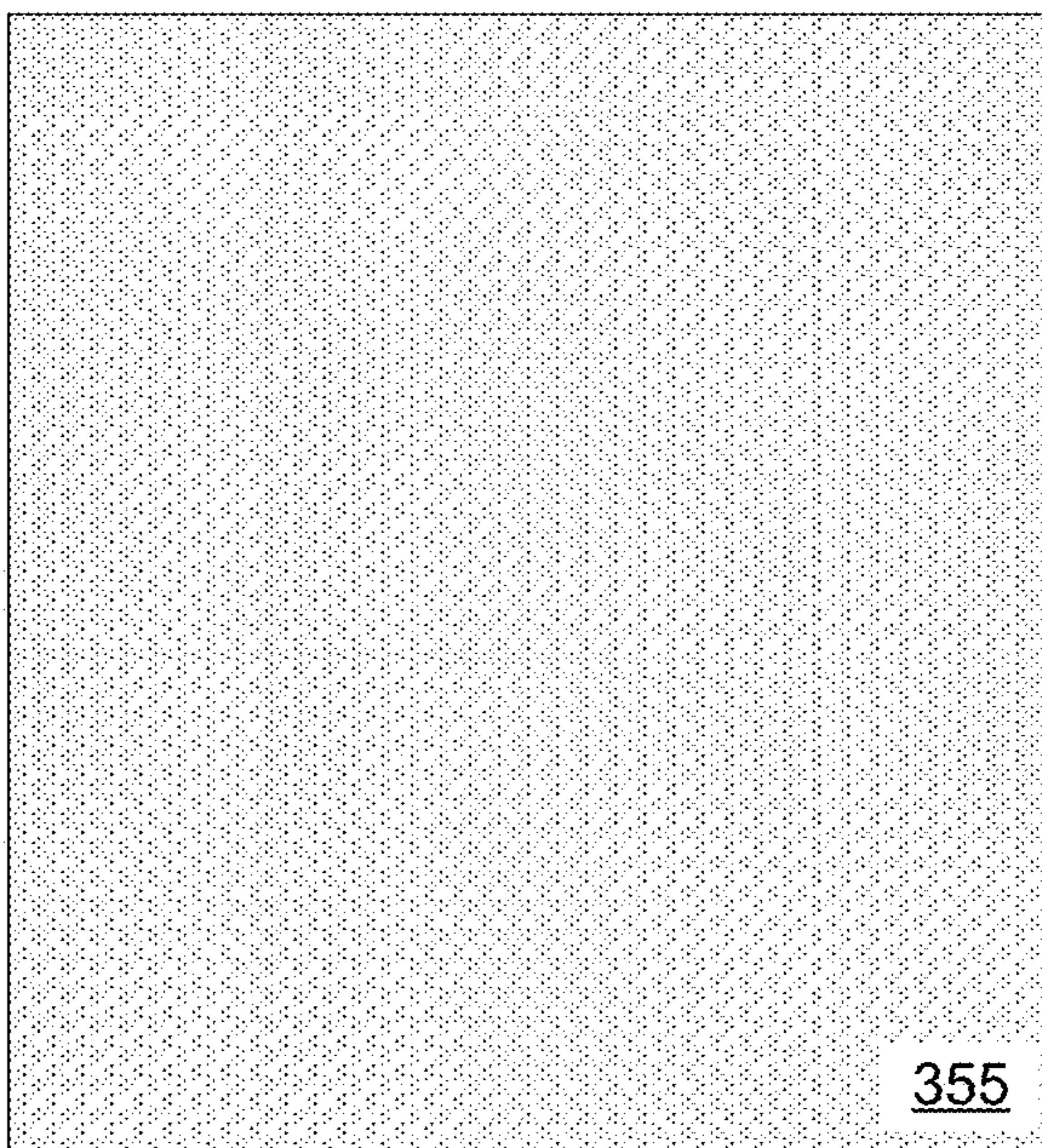
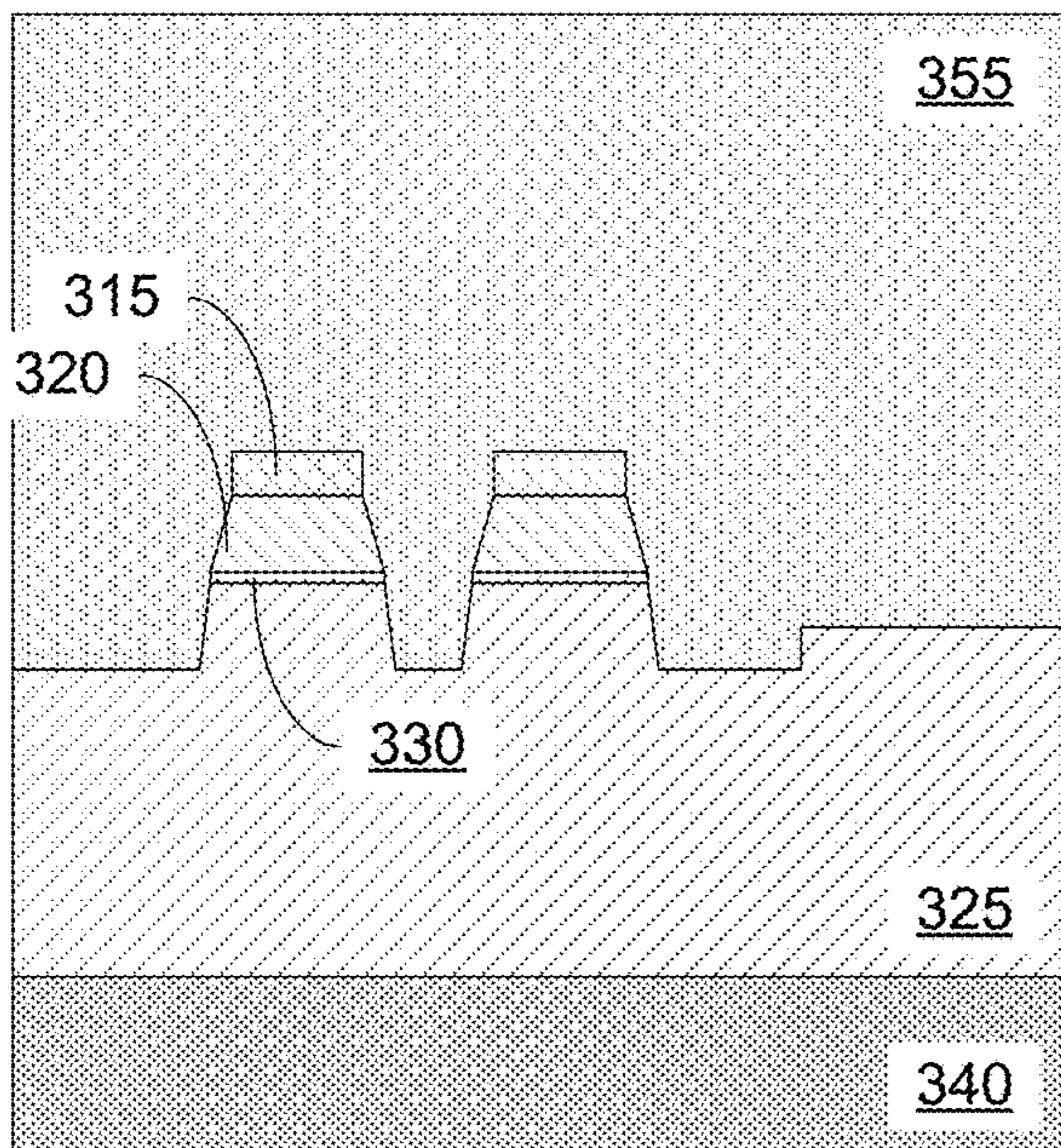


FIG. 3G

300H

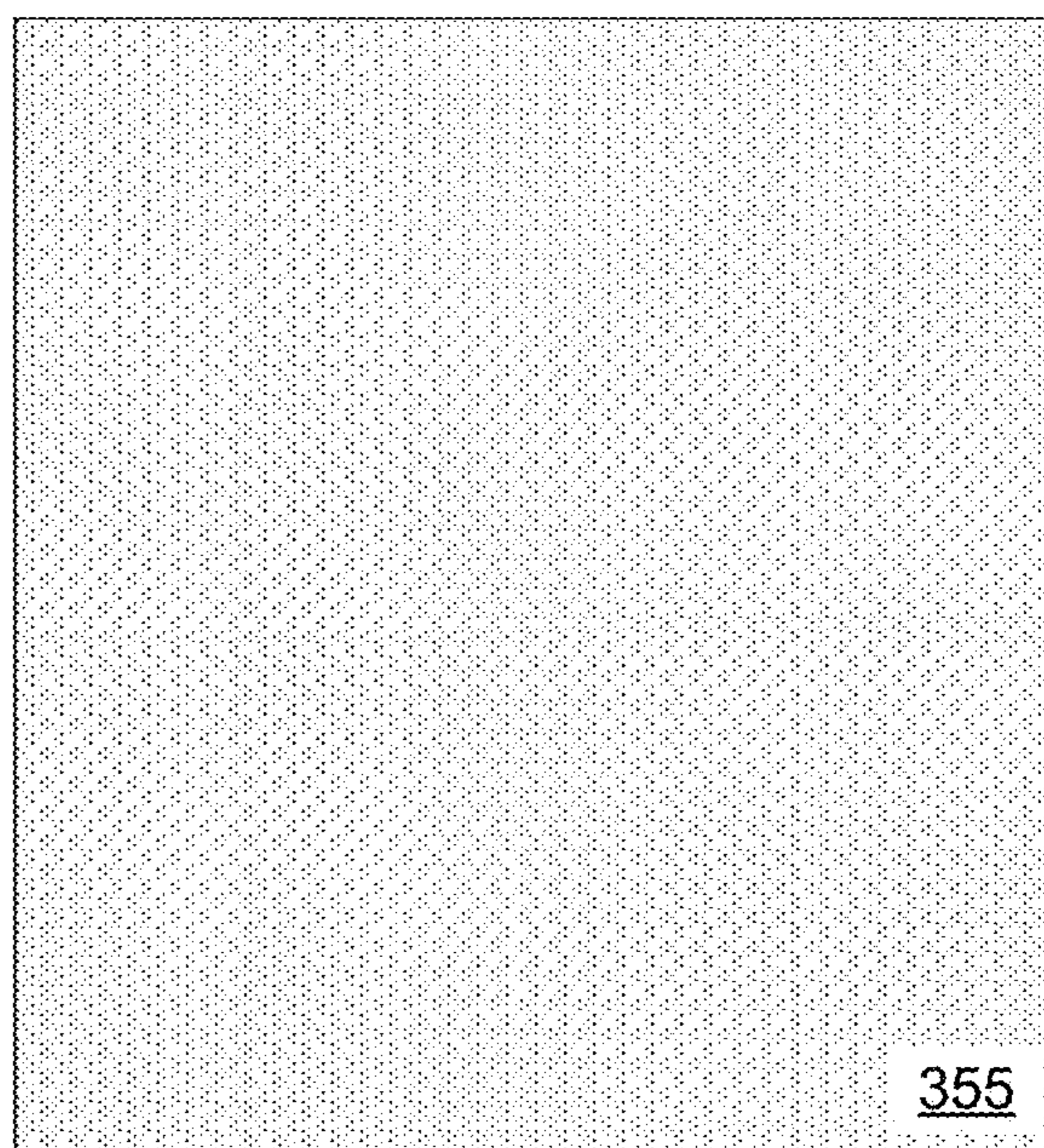
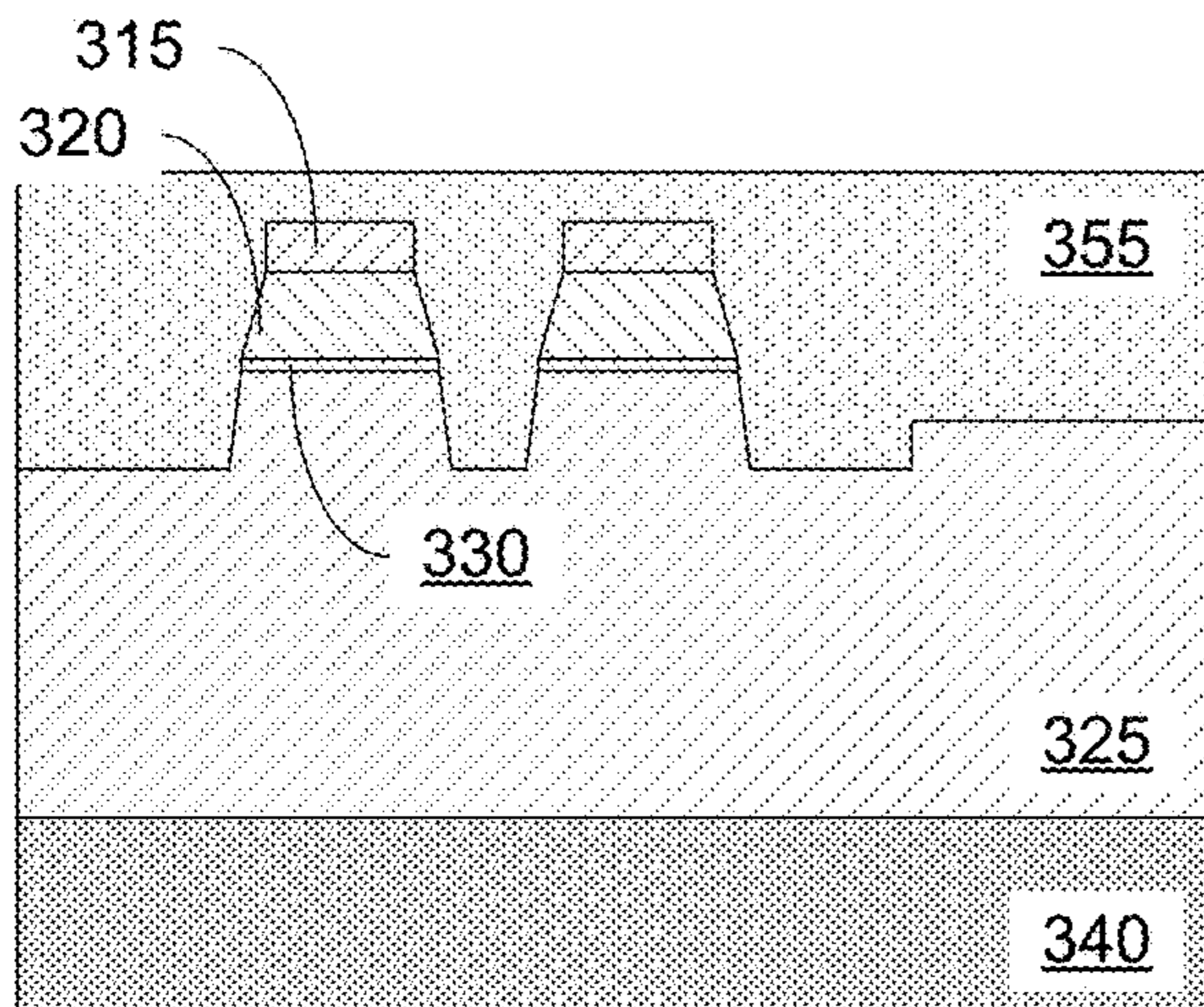


FIG. 3H

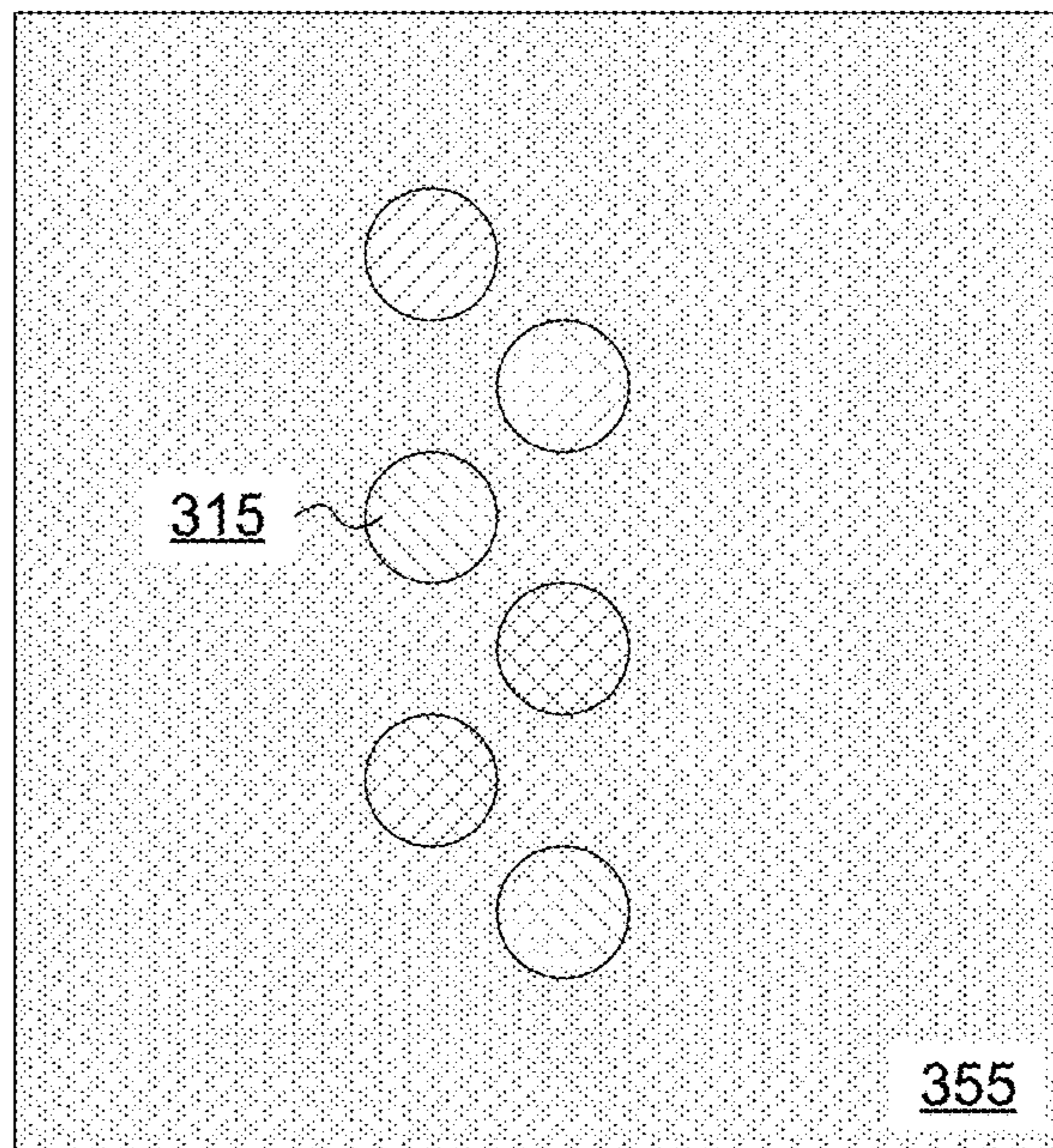
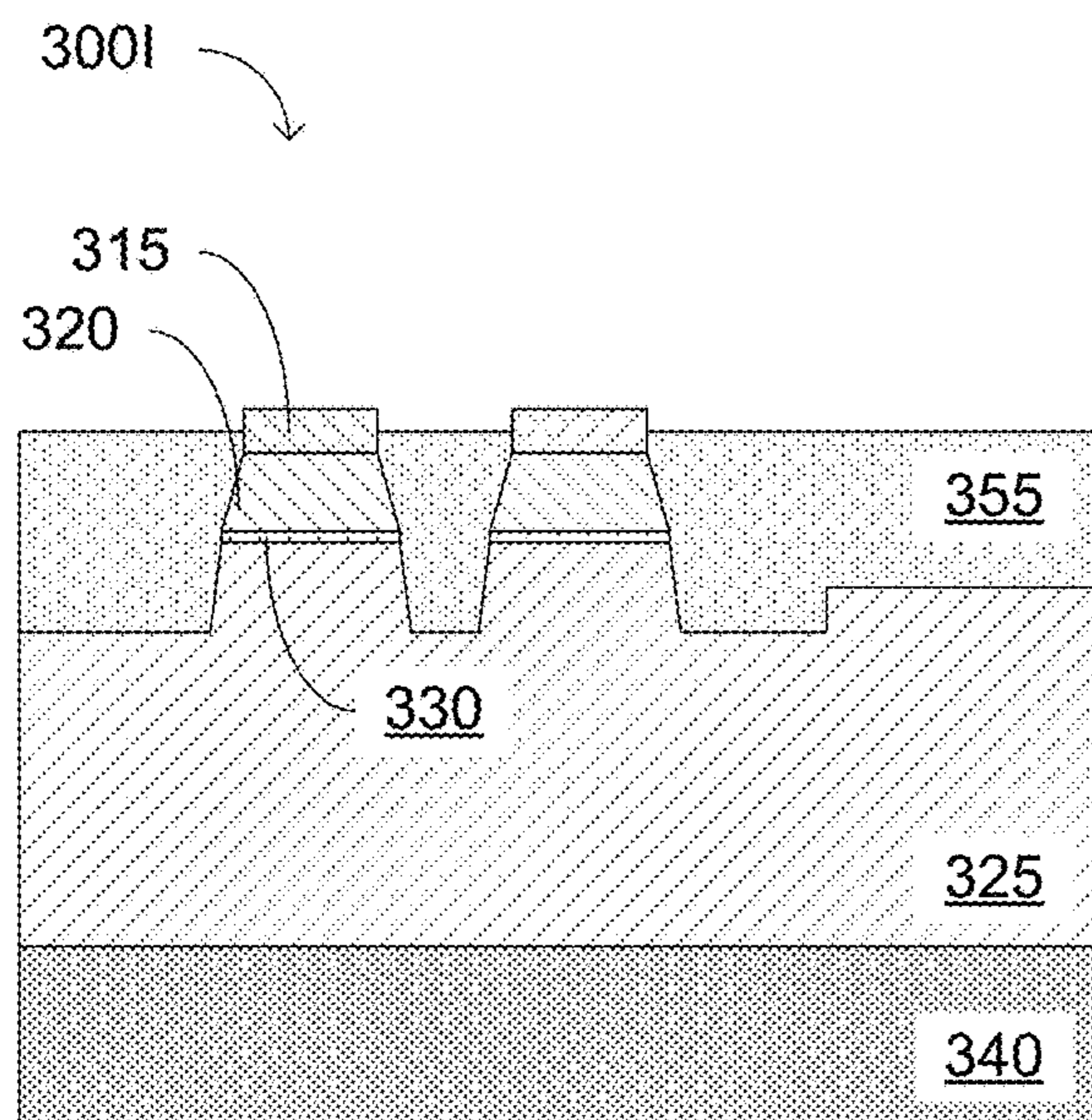


FIG. 3I

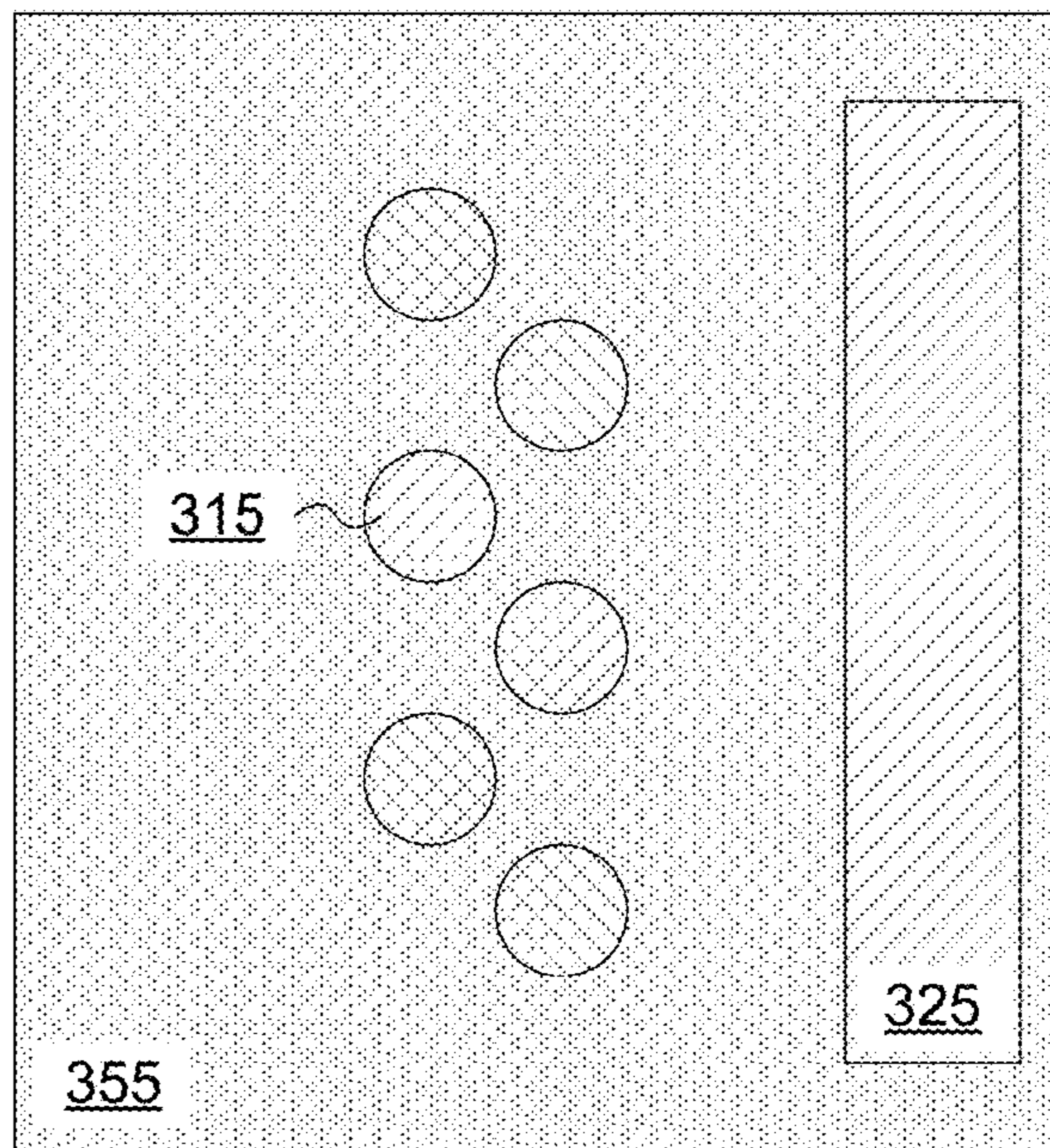
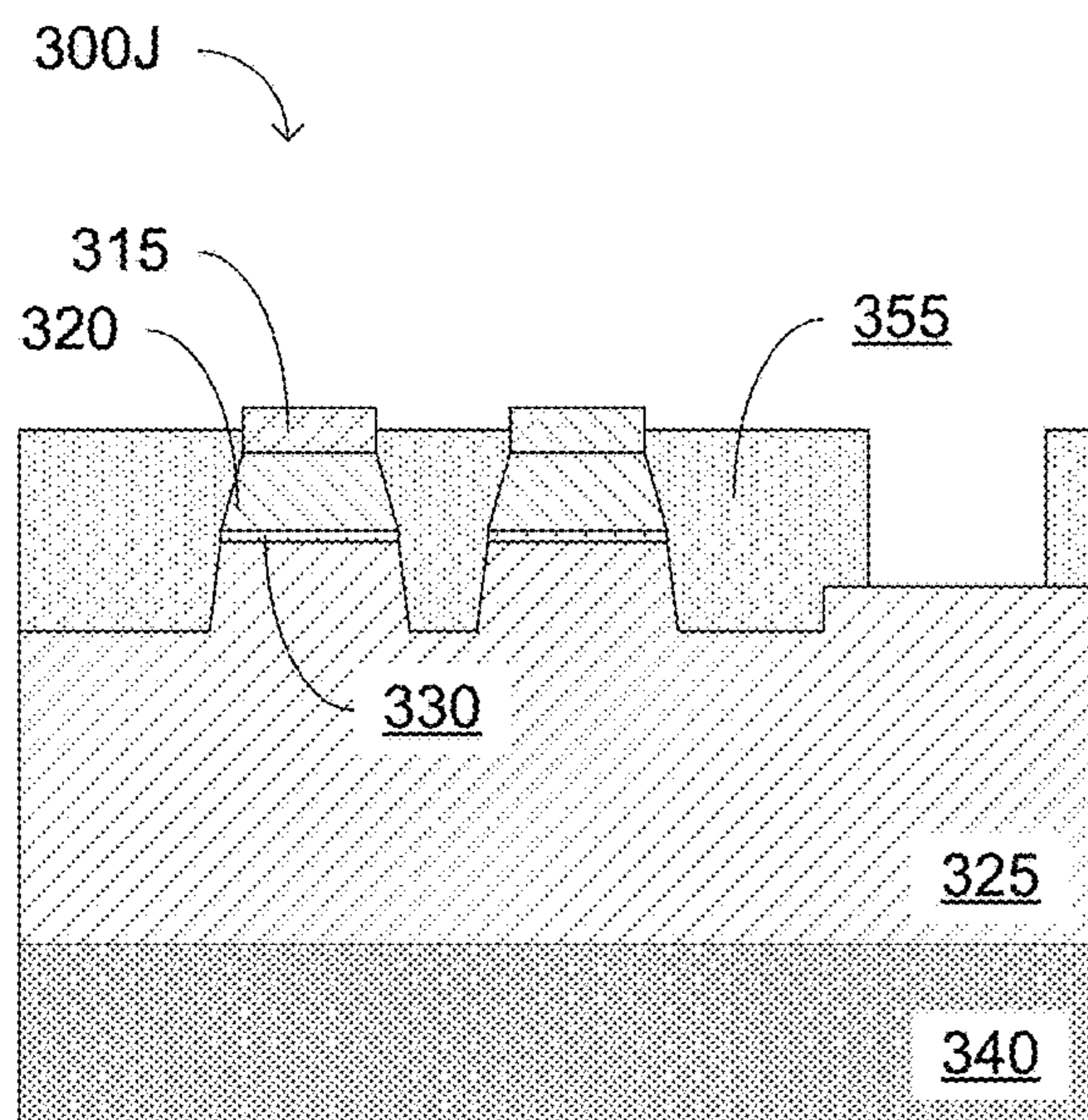


FIG. 3J

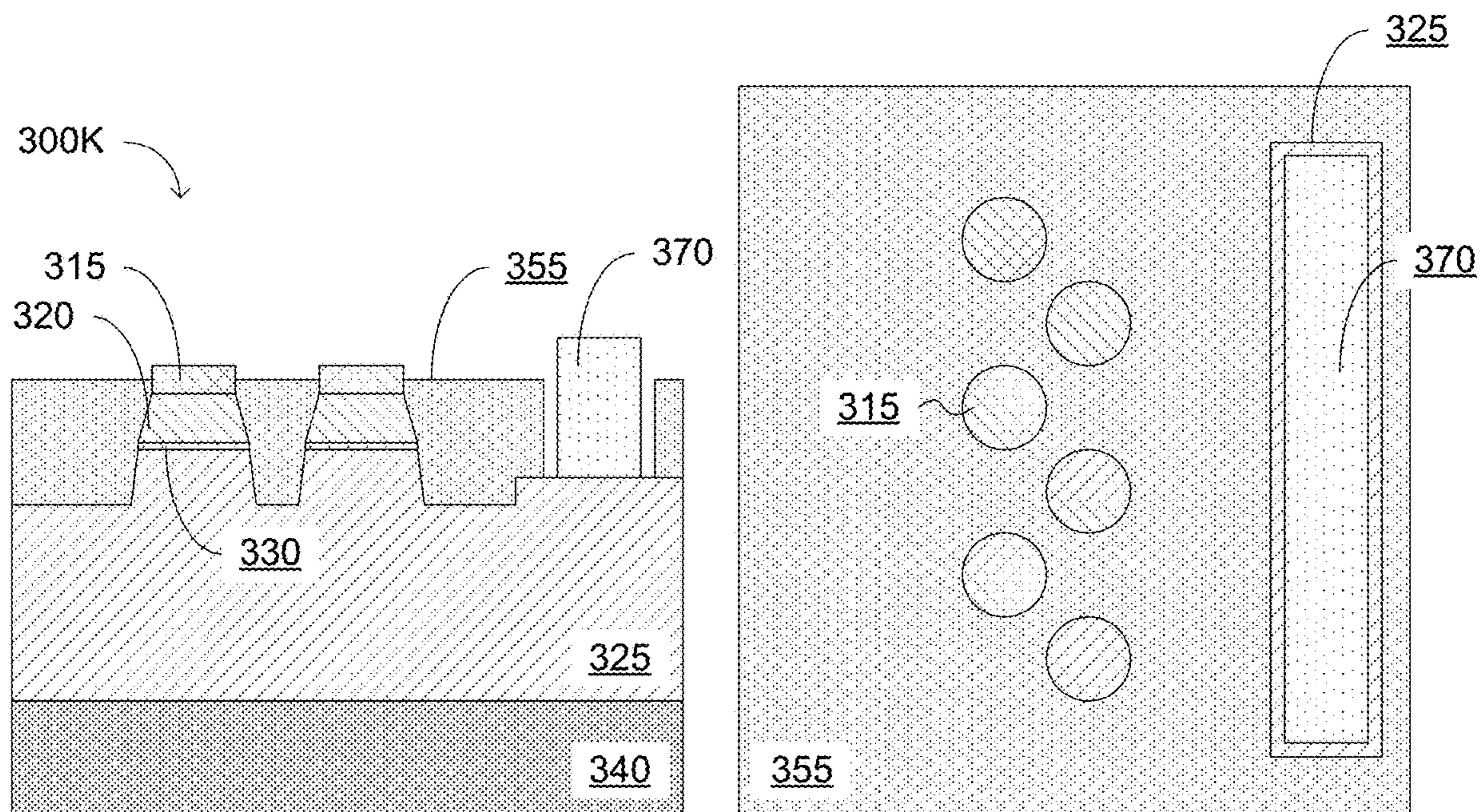


FIG. 3K

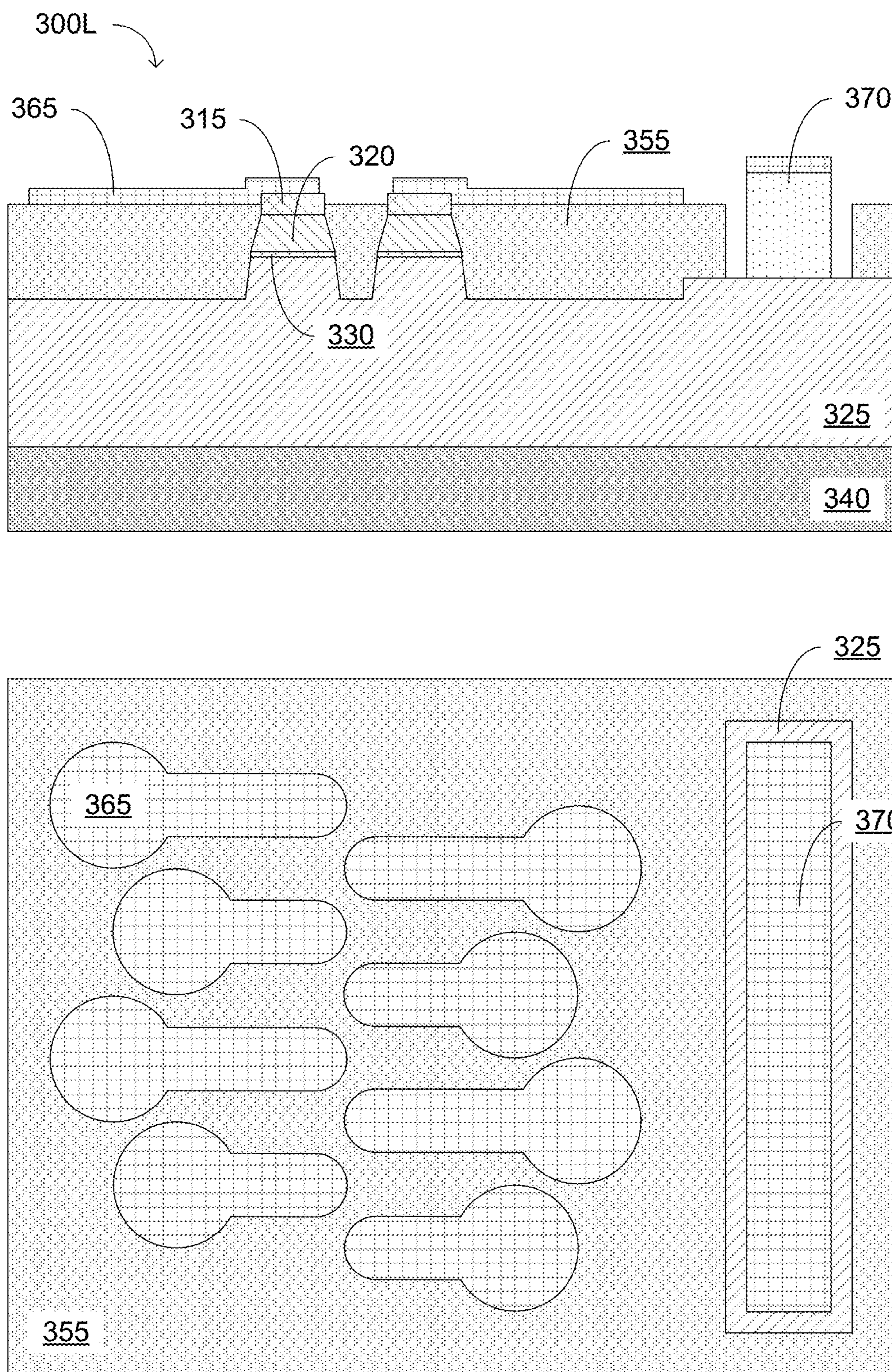


FIG. 3L

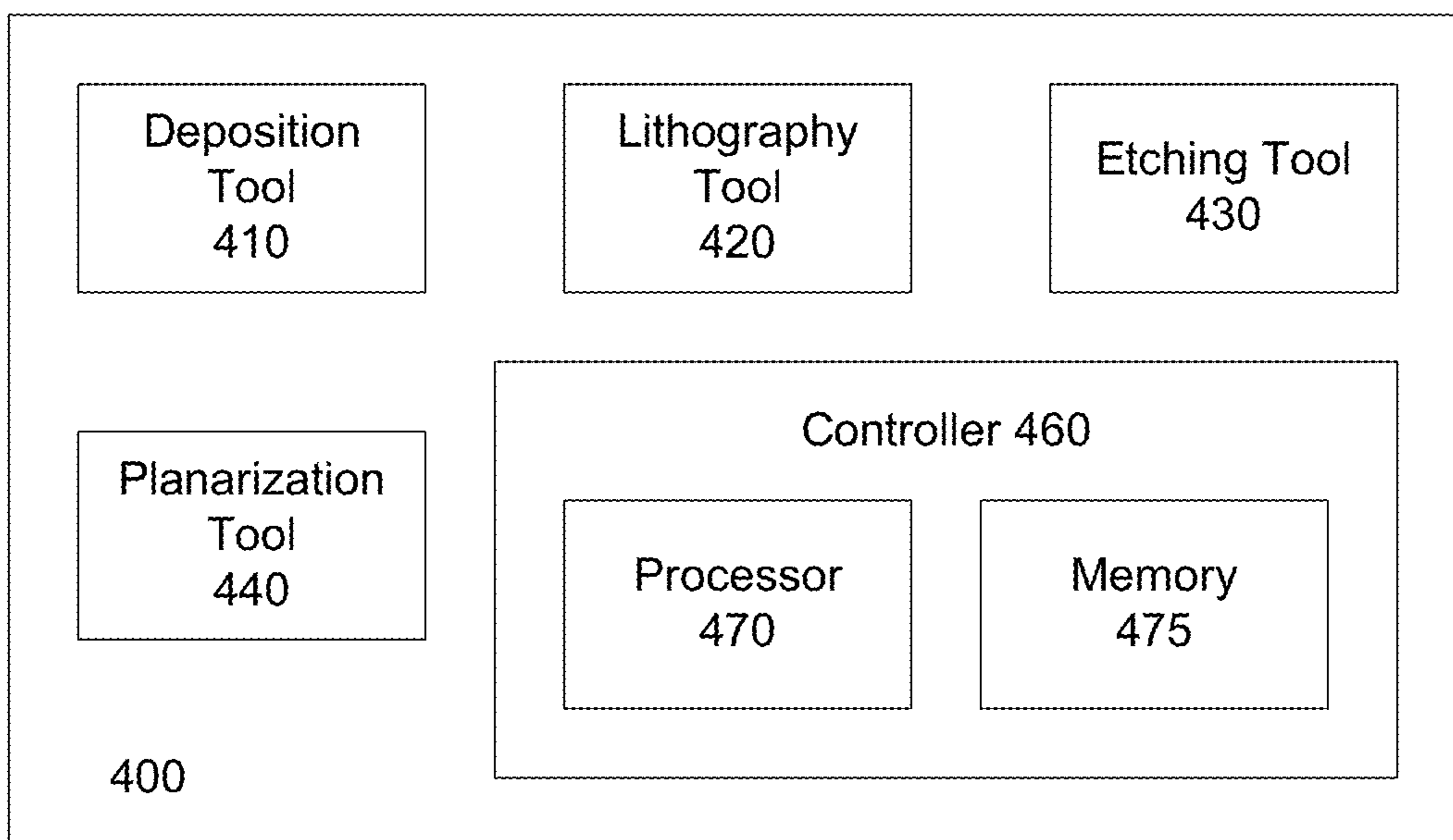


FIG. 4

SELF-ALIGNMENT OF MICRO LIGHT EMITTING DIODE USING PLANARIZATION

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. application Ser. No. 16/801,118, filed Feb. 25, 2020, which is a continuation of U.S. application Ser. No. 15/958,316, filed Apr. 20, 2018, now U.S. Pat. No. 10,615,305, all of which are incorporated by reference in their entirety.

BACKGROUND OF THE INVENTION

1. Field of the Disclosure

[0002] The present disclosure relates to micro LED (μ LED) fabrication and more specifically to μ LED fabrication using self-alignment.

2. Description of the Related Art

[0003] Micro light-emitting diode (μ LED) display are an emerging flat panel display technology that includes microscopic light-emitting diodes (LEDs) for displaying images. Compared to liquid crystal display (LCD) technology, μ LED display devices offer improved contrast, faster response time, and lower energy consumption. However, as the size of μ LEDs decreases, the alignment constraints for the μ LEDs becomes more strict. Such strict alignment constraints increases the difficulty in fabricating the μ LEDs.

SUMMARY

[0004] Embodiments relate to a micro light-emitting-diode (μ LED) fabricated using a self-aligned process. To fabricate the μ LED, a metal layer is deposited on a p-type semiconductor. The p-type semiconductor is on an n-type semiconductor. The metal layer is patterned to define a p-metal. The p-type semiconductor is etched using the p-metal as an etch mask. Similarly, the n-type semiconductor is etched using the p-metal and the p-type semiconductor as an etch mask to define individual micro LEDs.

[0005] In some embodiments, a planarization layer is deposited. The planarization layer is then etched to expose the patterned p-metal. As such, both the p-n junction and the contact hole for the p-metal are both self-aligned to the p-metal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The teachings of the embodiments can be readily understood by considering the following detailed description in conjunction with the accompanying drawings.

[0007] Figure (FIG. 1 illustrates a cross-sectional view of micro light-emitting diodes (μ LED), according to one embodiment.

[0008] FIG. 2 illustrates a flowchart of a process for fabricating a μ LED, according to one embodiment.

[0009] FIGS. 3A-3L illustrate cross-sectional views and top views of various fabrication steps of μ LEDs, according to one embodiment.

[0010] FIG. 4 illustrates a block diagram of a device for manufacturing the μ LEDs.

DETAILED DESCRIPTION OF EMBODIMENTS

[0011] The Figures (FIG.) and the following description relate to preferred embodiments by way of illustration only. It should be noted that from the following discussion, alternative embodiments of the structures and methods disclosed herein will be readily recognized as viable alternatives that may be employed without departing from the principles of the embodiments.

[0012] Reference will now be made in detail to several embodiments, examples of which are illustrated in the accompanying figures. It is noted that wherever practicable, similar or like reference numbers may be used in the figures and may indicate similar or like functionality. The figures depict embodiments for purposes of illustration only.

[0013] Embodiments relate to a process for fabricating micro light-emitting diodes (μ LED). The fabrication process disclosed herein uses a self-aligned process to form p-electrodes on a p-doped semiconductor layer (e.g., Gallium Nitride) to form one or more μ LEDs.

[0014] FIG. 1 illustrates a cross-sectional view of micro light-emitting diodes (μ LED), according to one embodiment. FIG. 1 illustrates two μ LEDs 105A, 105B (collectively referred to as " μ LEDs 105" hereinafter) and an n-electrode 150. Each of the μ LEDs 105 include a p-type layer 120, an n-type layer 125, and a quantum well (QW) 130. In some embodiments, the p-type layer and the n-type layer are doped gallium nitride (GaN) layers. In some embodiments, the GaN layers are grown on top of a transparent substrate 140. For instance, the transparent substrate may be a sapphire substrate or an indium tin oxide (ITO) substrate.

[0015] The μ LEDs 105 further include a p-electrode 115 over the p-type layer 120 and a contact 110 for connecting to the p-electrode 115. In some embodiments, multiple μ LEDs share a single n-electrode 150. For instance, the n-electrode may be coupled to ground or a negative supply voltage. Moreover, each μ LED may have a separate p-electrode, such that each μ LED may be independently controlled. Each of the LEDs 105 may include additional layers such as a barrier layer not illustrated in FIG. 1.

[0016] FIG. 2 illustrates a flowchart of a process for fabricating an μ LED, according to one embodiment. FIGS. 3A through 3L show cross-sectional views and top views of μ LEDs at various steps of the process illustrated in FIG. 2. The self-aligned μ LED fabrication process starts with a stack 300A including a substrate 340, an n-type layer 325 (e.g., n-type gallium nitride (N-GaN)), a quantum well (QW) 330, and a p-type layer 320 (e.g., p-type gallium nitride (P-GaN)). FIG. 3A illustrates the stack at the beginning of the flow shown in FIG. 2.

[0017] The stack 300A is etched 201 to expose the n-type layer 325, resulting in stack 300B illustrated in FIG. 3B. In some embodiments, the stack is etched using dry etching. In one embodiment, the dry etching is stopped approximately 300 nm below the QW 330.

[0018] In one embodiments, the amount of etching is controlled by using selective etching methods that has a selectivity in etching rate between the n-type layer 325, the p-type layer 320, and the QW 330. That is, an etching method that as an etching rate that is preferential to the p-type layer 320 is first used to etch the p-type layer 320 until the p-type layer is completely etched. Depending on the selectivity of the etching method, the etching method for etching the p-type layer is performed for an amount of time

longer than what is expected for completely etching the height of the p-type layer without the risk of a substantial etch in the n-type layer **320**.

[0019] In other embodiments, if the etching method is not selective between the p-type layer **320** and the n-type layer **325**, the amount of etching is controlled by calculating the time to etch the height of the p-type layer **320** and a predetermined height (e.g., 300 nm) of the n-type layer **325**. The time is calculated based on an etching rate for the p-type layer and the n-type layer of the etching method being used.

[0020] P-metal **315** is deposited **203** on the p-type layer **320** resulting stack **300C** illustrated in FIG. **3C**. The p-metal **315** may be made of nickel gold (NiAu) or other similar metal. In some embodiments, an adhesion layer is deposited before depositing the p-metal to aid the adhesion of the p-metal **315** and the p-type layer **320**.

[0021] The stack **300C** is patterned **205** to form the μ LED mesa structures. To pattern the μ LED mesa structures, photoresist **345** is applied and patterned to form the stack **300D** illustrated in FIG. **3D**. The stack **300D** is then etched to form the structure illustrated in FIG. **3E**. In some embodiments, the p-metal is wet etched to form an undercut. Furthermore, the p-type layer **320**, QW **330**, and the n-type layer **325** may be dry etched to achieve a desired profile. After then μ LED mesas have been etched, the photoresist **345** is removed as shown in FIG. **3F**.

[0022] As a result, the p-metal is self-aligned onto the μ LED mesa as illustrated in FIG. **3F**. Because the p-metal is formed on the μ LED mesa through a self-aligned process, a separate alignment step for aligning the p-metal to the μ LED mesa can be removed, and the alignment between the p-metal and the μ LED mesa is improved. By having the p-metal to be self-aligned to the μ LED mesa, the fabrication of the μ LEDs with higher misalignment tolerances is enabled and obviates the use of expensive alignment steps.

[0023] As shown in FIG. **3G**, a layer of an insulation layer **355** such as a polymer including benzocyclobutene (BCB) is deposited **207**. For example, a polymer may be spin coated onto the substrate and subsequently cured. In other embodiments, other polymers may be used instead of BCB. In yet other embodiments, nitrides or oxides are used instead of polymers for the insulation layer **355**. In some embodiments, the insulation layer **355** is also used as a planarization layer. In some embodiments, the insulation layer **355** is used to isolate the μ LEDs. In some embodiments, other insulators such as oxides or nitrides is deposited as the insulation layer **355**. Then, as shown in FIG. **3H**, the insulation layer **355** is planarized **209** and thinned down using chemical-mechanical polishing (CMP) process. Subsequently, as shown in FIG. **3I**, the insulation layer **355** is etched **211** using dry etching to expose the p-metal **315**. In some embodiments, the insulation layer **355** is etched using end-point detection, where interferometry, reflectometry, and/or spectrometry is used to determine a thickness of a layer, or whether a specific material is exposed to determine an end point of an etching step. That is, in some embodiments, the thickness of the insulation layer is periodically measured to determine whether the etching of the insulation layer **355** is complete. In other embodiments, a determination is made whether the p-metal is exposed to determine whether the etching of the insulation layer **355** is complete.

[0024] In some embodiments, the insulation etching is stopped after the p-metal layer has been exposed and before the p-type layer is exposed. As such, metal layer may be

deposited on top of the p-metal and the insulation layer to route the p-metal to other locations. In some embodiments, the p-metal is routed to contact pads to allow an electrical connection to be made with the p-metal. In this embodiment, the thickness of the p-metal may be chosen based on the accuracy of end-point detection method used to etch the insulation layer **355**. For instance, the thickness of the p-metal is chosen to be larger than the margin of error of the end-point detection method used.

[0025] As such, the exposure of the p-metal is self-aligned to the p-metal **315** itself. That is, the p-metal can be completely exposed without exposing the layers underneath the p-metal without using an alignment step. This relaxes the constraint for an accurate alignment method and allows fabrication of μ LEDs with smaller feature sizes and pitch sizes. That is, the opening of the p-metal **315** is achieved without an additional alignment step. By having the opening of the p-metal to be self-aligned, the fabrication of the μ LEDs with higher misalignment tolerances can be enabled and obviates the use of expensive alignment steps.

[0026] N-metal **370** is deposited **213**. In some embodiments, as show in FIG. **3J**, the region where the n-metal **370** is to be located is etched to expose the n-type layer **325** before depositing the n-metal **370**. Furthermore, as shown in FIG. **3K**, after depositing a metal layer for forming the n-metal **370**, the deposited metal layer may be patterned.

[0027] Bond metal **365** is deposited **215**. In some embodiments, the bond metal is deposited on top of the p-metal **315** and on top of the n-metal **370**. In some embodiments, the bond metal is a titanium-gold (TiAu) alloy. In some embodiments, the bond metal **365** is patterned form bond pads and track lines connecting the bond pads to the p-metal. In some embodiments, additional layers, such as a passivation layer and a seed metal layer is deposited on top of the stack **300L** of FIG. **3L**.

[0028] As such, the two alignment steps for aligning the p-metal **115** to the p-layer **120**, and for exposing the p-metal are eliminated. Thus, the disclosed process allows the fabrication of a μ LED without any alignment steps, reducing the complexity of the fabrication process.

[0029] FIG. **4** illustrates a block diagram of a device **400** for manufacturing the μ LEDs. The device **400** includes a deposition tool **410**, a lithography tool **420**, an etching tool **430**, a planarization tool, and a controller **460**.

[0030] The deposition tool **410** deposits layers of material onto a substrate. The deposition tool **410** may use techniques such as molecular beam epitaxy (MBE) or chemical vapor deposition (CVD) to deposit or grow layers of material onto a substrate.

[0031] The lithography tool **420** transfers geometric patterns from a photomask to a light-sensitive chemical photoresist. The lithography tool **420** may include tools to deposit or spin coat photoresist onto a substrate, align the photomask to the substrate, expose the photoresist, and develop the photoresist. In some embodiments, the lithography tool further includes tools to remove the photoresist from the substrate.

[0032] The etching tool **430** chemically or physically removes layers from the surface of a substrate. The etching tool **430** may include tools for performing wet etching and/or dry etching. The etching tool **430** may be configured to follow pre-determined recipes based on the type of material being etched. In some embodiments, the etching tool **430** includes an end-point detection functionality that

periodically or continuously determines the thickness of the layer being etched, or whether a certain layer has been exposed to determine the end-point of the etching process.

[0033] The planarization tool **440** smooths or planarizes the surface of a substrate using chemical and/or mechanical forces. The planarization tool **440** uses an abrasive chemical slurry and a polishing pad to planarize the surface of the substrate.

[0034] The controller **460** controls the fabrication process of the μ LEDs. The controller **460** includes a processor **470** and a memory **475**. The memory **475** stores the sequence of steps and the recipes to be followed for fabricating the μ LEDs. For instance, the memory **475** stores the steps illustrated in the flowchart of FIG. 2. The processor retrieves the steps stored in memory **475** and instructs each of the tools **410**, **420**, and **430** to perform the steps for fabricating the μ LEDs.

[0035] Upon reading this disclosure, those of ordinary skill in the art will appreciate still additional alternative structural and functional designs through the disclosed principles of the embodiments. Thus, while particular embodiments and applications have been illustrated and described, it is to be understood that the embodiments are not limited to the precise construction and components disclosed herein and that various modifications, changes and variations which will be apparent to those skilled in the art may be made in the arrangement, operation and details of the method and apparatus disclosed herein without departing from the spirit and scope as defined in the appended claims.

1. A method of fabricating a light emitting diode (LED) device, comprising:

forming a metal contact on a surface of a semiconductor stack comprising a p-type semiconductor and an n-type semiconductor;

etching the semiconductor stack to define the LED, wherein the metal contact is configured to selectively mask the semiconductor stack to pattern the semiconductor stack;

depositing a planarization layer over the LED;

etching the planarization layer to expose the metal contact, wherein the etching of the planarization layer and the etching of the semiconductor stack are both aligned to the metal contact.

2. The method of claim **1**, wherein the planarization layer is deposited over the metal contact used for selectively masking the etching of the semiconductor stack.

3. The method of claim **1**, wherein the deposited planarization layer has a first region disposed over the metal contact used for selectively masking the etching of the semiconductor stack, the first region having a first thickness, and a second region around the first region, the second region having a second thickness larger than the first thickness, and wherein etching the planarization layer comprises removing the first region to expose the metal contact, and etching the second region by at least the first thickness.

4. The method of claim **1**, wherein forming the metal contact on the surface of the semiconductor stack comprises: depositing a metal layer directly on a semiconductor stack; and

patterning the metal layer to define the metal contact.

5. The method of claim **1**, wherein the etching of the planarization layer and the etching of the semiconductor stack are both self-aligned to the metal contact.

6. The method of claim **1**, wherein the etching of the planarization layer is performed by at least a chemical-mechanical polishing (CMP) process followed by a dry-etching process on the planarization layer.

7. The method of claim **6**, wherein the dry-etching process is stopped when a thickness of the planarization layer is equal to or lower than a preset thickness.

8. The method of claim **6**, wherein the dry-etching process is stopped after the metal contact is exposed but before a top surface of the semiconductor stack is exposed.

9. The method of claim **1**, wherein etching the planarization layer to expose the metal contact comprises:

planarizing the planarization layer; and

etching the planarized planarization layer to expose the metal contact without exposing a top surface of the semiconductor stack.

10. A light emitting diode (LED) fabricated by a process comprising the steps of:

forming a metal contact on a surface of a semiconductor stack comprising a p-type semiconductor and an n-type semiconductor;

etching the semiconductor stack to define the LED, wherein the metal contact is configured to selectively mask the semiconductor stack to pattern the semiconductor stack;

depositing a planarization layer over the LED;

etching the planarization layer to expose the metal contact, wherein the etching of the planarization layer and the etching of the semiconductor stack are both aligned to the metal contact.

11. The LED of claim **10**, wherein the planarization layer is deposited over the metal contact used for selectively masking the etching of the semiconductor stack.

12. The LED of claim **10**, wherein the deposited planarization layer has a first region disposed over the metal contact used for selectively masking the etching of the semiconductor stack, the first region having a first thickness, and a second region around the first region, the second region having a second thickness larger than the first thickness, and wherein etching the planarization layer comprises removing the first region to expose the metal contact, and etching the second region by at least the first thickness.

13. The LED of claim **10**, wherein forming the metal contact on the surface of the semiconductor stack comprises:

depositing a metal layer directly on a semiconductor stack; and

patterning the metal layer to define the metal contact.

14. The LED of claim **10**, wherein the etching of the planarization layer and the etching of the semiconductor stack are both self-aligned to the metal contact.

15. The LED of claim **10**, wherein the etching of the planarization layer is performed by at least a chemical-mechanical polishing (CMP) process followed by a dry-etching process on the planarization layer.

16. The LED of claim **15**, wherein the dry-etching process is stopped when a thickness of the planarization layer is equal to or lower than a preset thickness.

17. The LED of claim **15**, wherein the dry-etching process is stopped after the metal contact is exposed but before a top surface of the semiconductor stack is exposed.

18. The LED of claim **10**, wherein etching the planarization layer to expose the metal contact comprises:

planarizing the planarization layer; and
etching the planarized planarization layer to expose the metal contact without exposing a top surface of the semiconductor stack.

19. A non-transitory computer readable storage medium configured to store instructions, the instructions, when executed by a fabrication tool, cause the fabrication tool to:

forming a metal contact on a surface of a semiconductor stack comprising a p-type semiconductor and an n-type semiconductor;

etching the semiconductor stack to define the LED, wherein the metal contact is configured to selectively mask the semiconductor stack to pattern the semiconductor stack;

depositing a planarization layer over the LED;

etching the planarization layer to expose the metal contact, wherein the etching of the planarization layer and the etching of the semiconductor stack are both aligned to the metal contact.

20. The non-transitory computer readable storage medium of claim **19**, wherein the planarization layer is deposited over the metal contact used for selectively masking the etching of the semiconductor stack.

* * * * *