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(54) **SEMICONDUCTOR DEVICE AND METHOD FOR FABRICATING THE SAME**

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H01L 29/06 (2006.01)
H01L 21/8234 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 21/823462*** (2013.01); ***H01L 21/823431*** (2013.01)

(58) **Field of Classification Search**
CPC H01L 21/02164; H01L 21/02233; H01L 21/02269; H01L 21/0228; H01L 21/823462; H01L 21/823431; H01L 21/02532; H01L 29/0649; H01L 29/1054; H01L 29/66795; H01L 21/76224; H01L 29/7848; H01L 29/7849; H01L 29/785; H01L 29/7851
USPC 438/149, 197, 217, 275, 311, 424, 585; 257/368, 409, 623
See application file for complete search history.

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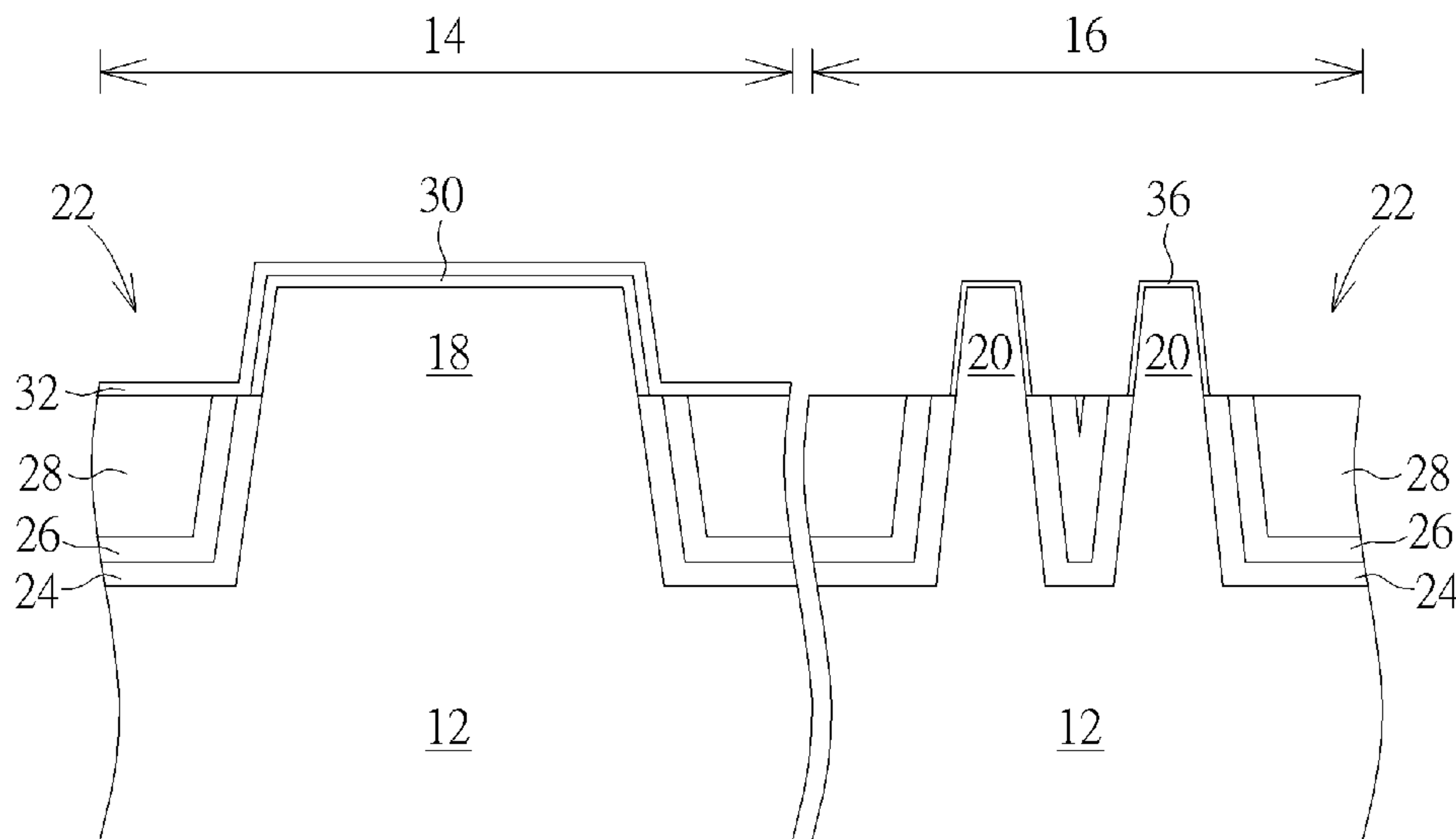
(57) **ABSTRACT**

A semiconductor device includes: a substrate having a first region and a second region; a first fin-shaped structure on the first region and a second fin-shaped structure on the second region; a shallow trench isolation (STI) around the first fin-shaped structure and the second fin-shaped structure; a first oxide layer on the first fin-shaped structure; a second oxide layer on and directly contacting the first oxide layer and the STI; and a third oxide layer on the second fin-shaped structure, wherein a thickness of the third oxide layer is less than a thickness of the first oxide layer.

5 Claims, 2 Drawing Sheets



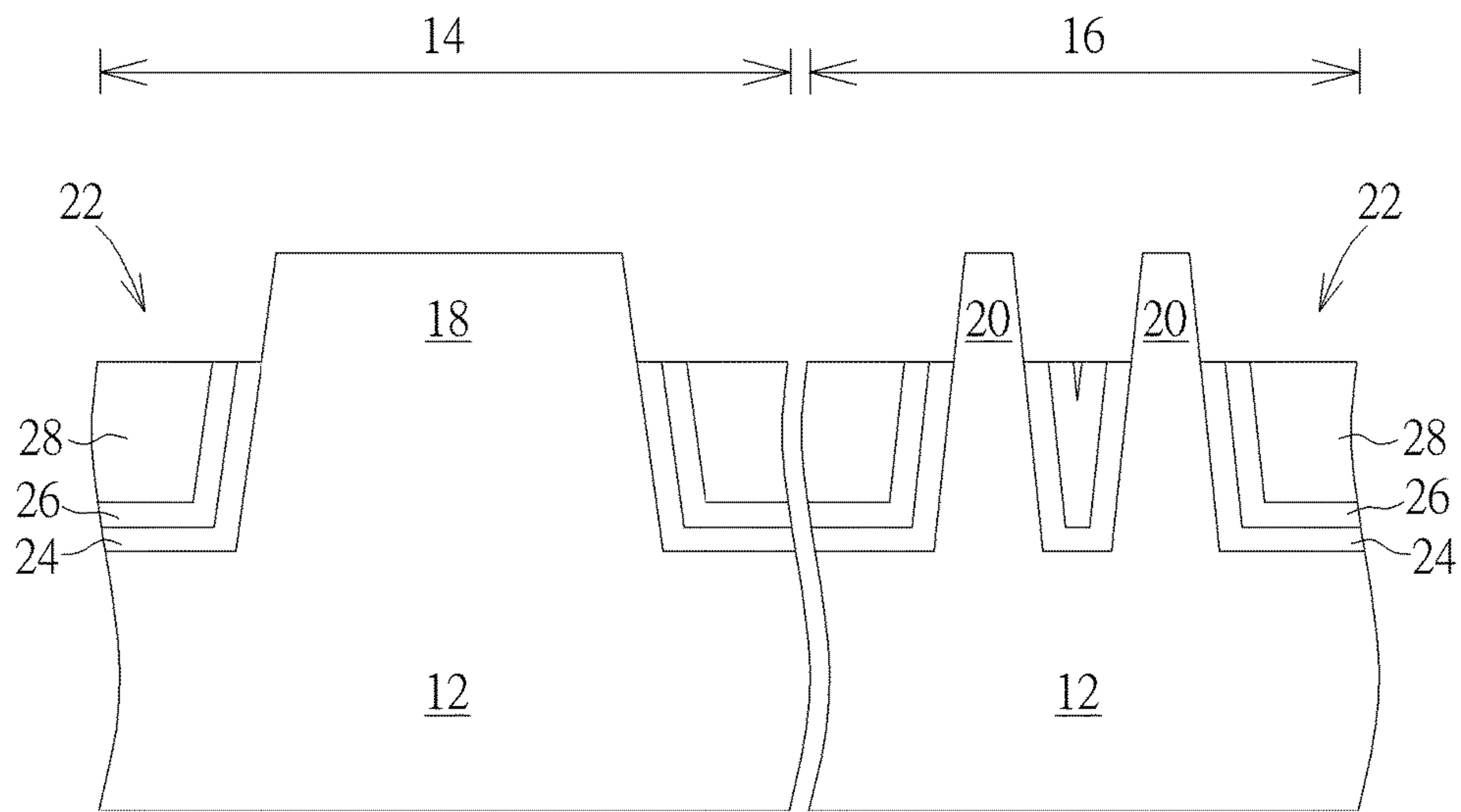


FIG. 1

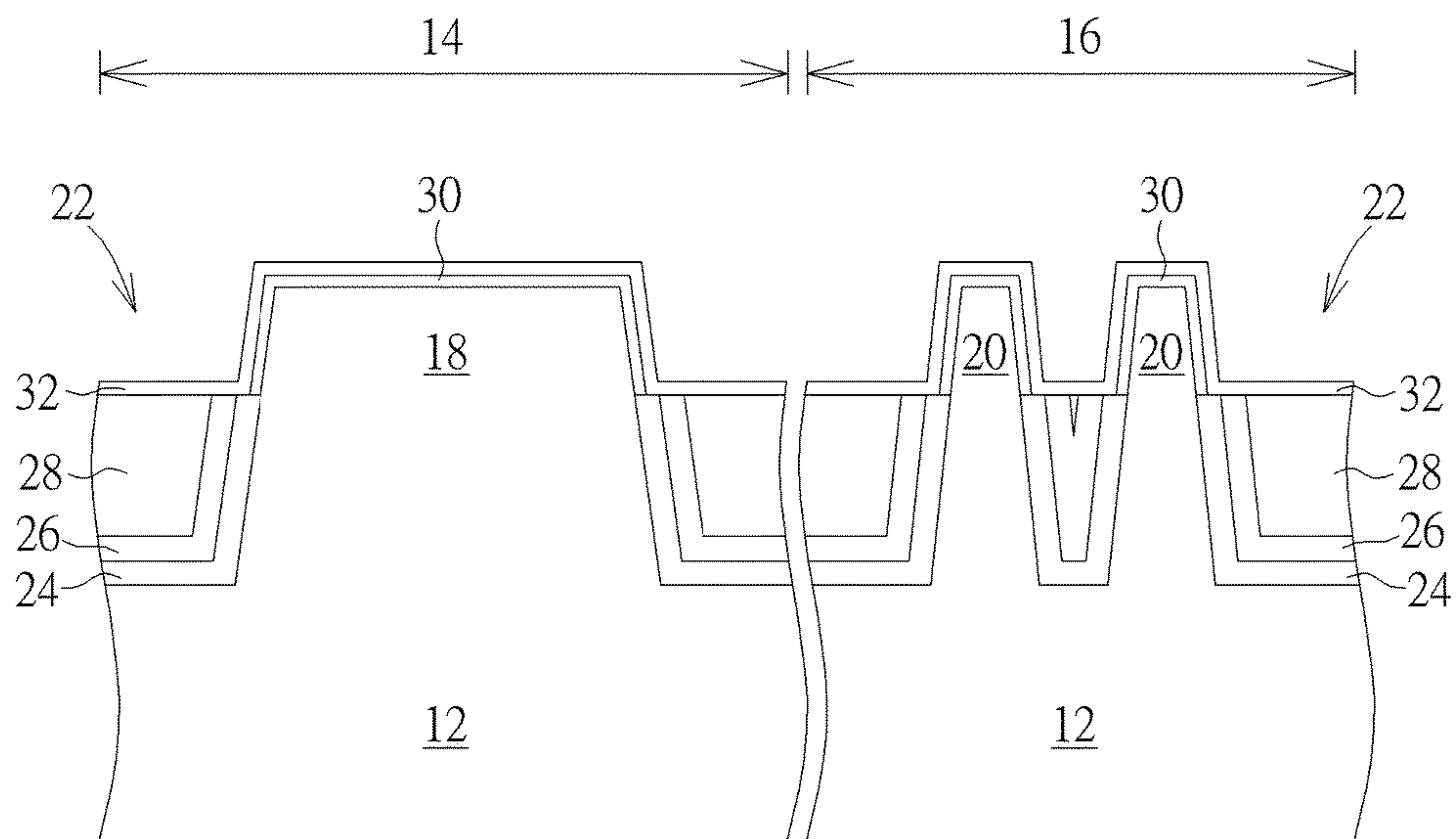


FIG. 2

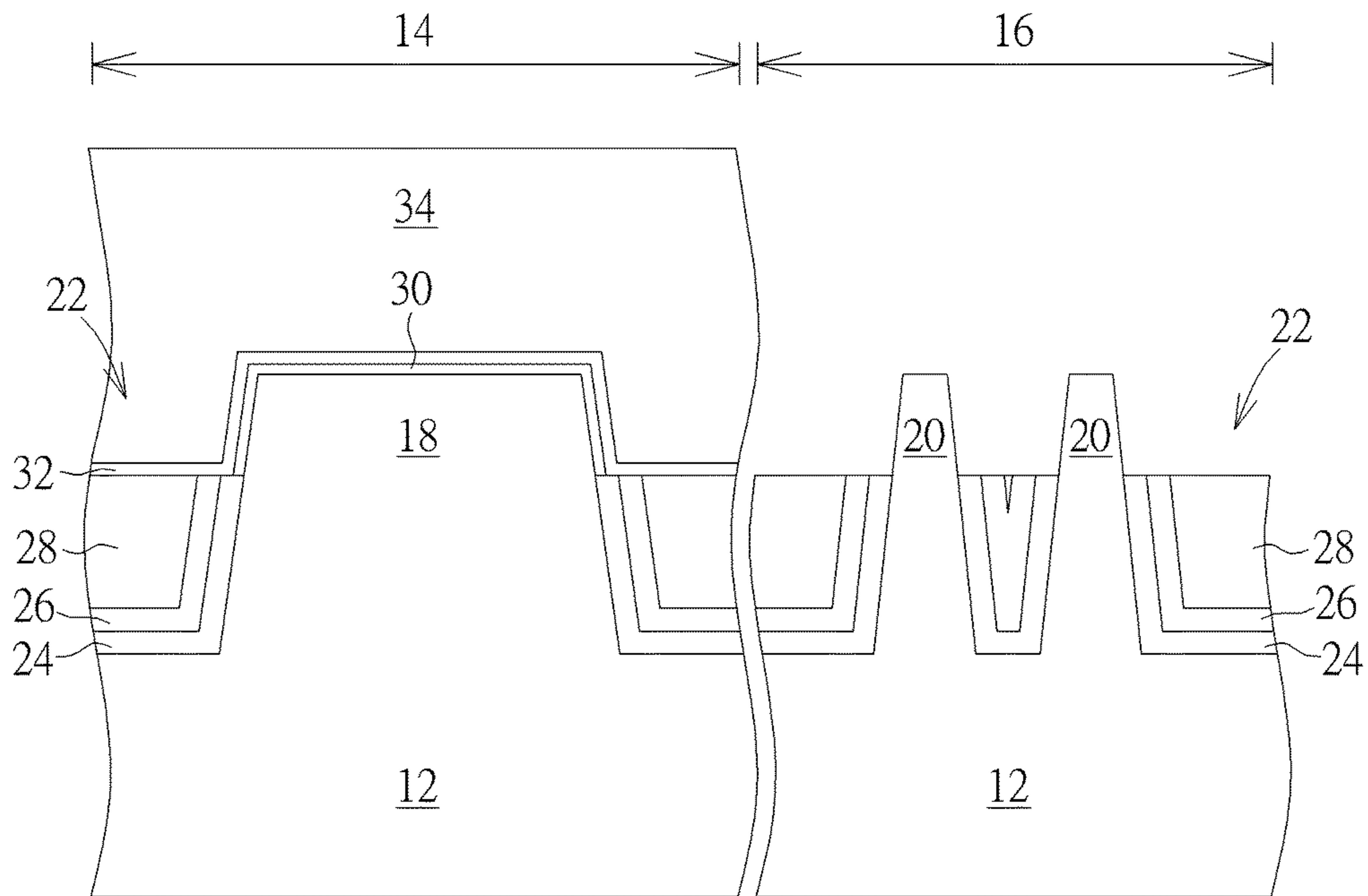


FIG. 3

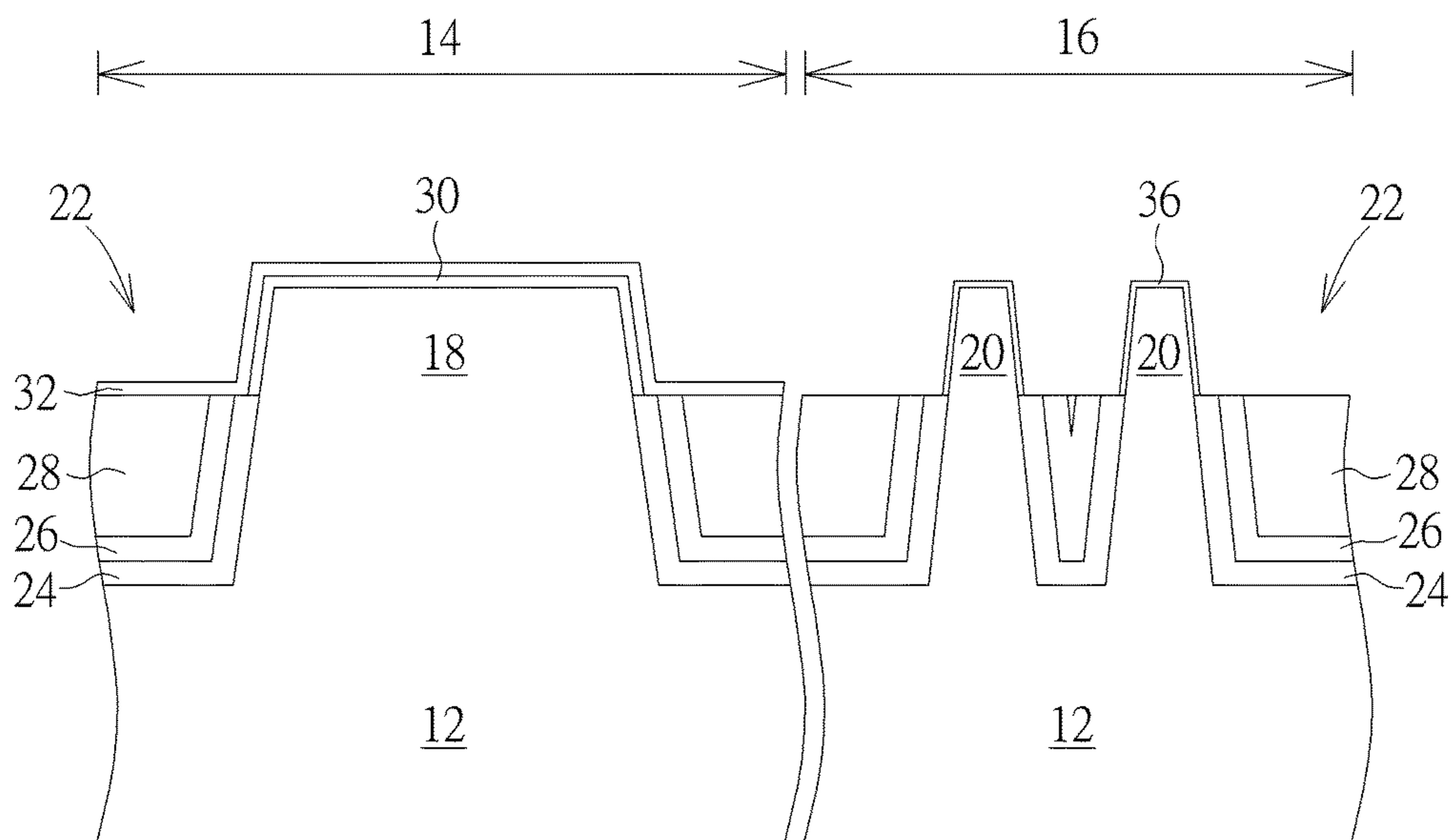


FIG. 4

SEMICONDUCTOR DEVICE AND METHOD FOR FABRICATING THE SAME

CROSS REFERENCE TO RELATED APPLICATIONS

This is a continuation application of U.S. patent application Ser. No. 15/618,131, filed on Jun. 9, 2017, and all benefits of such earlier application are hereby claimed for this new continuation application.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a method for fabricating semiconductor device, and more particularly to a method of integrating in-situ steam generation (ISSG) and atomic layer deposition (ALD processes to form gate dielectric layer on fin-shaped structures.

2. Description of the Prior Art

With the trend in the industry being towards scaling down the size of the metal oxide semiconductor transistors (MOS), three-dimensional or non-planar transistor technology, such as fin field effect transistor technology (FinFET) has been developed to replace planar MOS transistors. Since the three-dimensional structure of a FinFET increases the overlapping area between the gate and the fin-shaped structure of the silicon substrate, the channel region can therefore be more effectively controlled. This way, the drain-induced barrier lowering (DIBL) effect and the short channel effect are reduced. The channel region is also longer for an equivalent gate length, thus the current between the source and the drain is increased. In addition, the threshold voltage of the fin FET can be controlled by adjusting the work function of the gate.

However, current approach for forming gate oxide layer during fabrication of FinFET devices has found to be ineffective in that either too much silicon were consumed during the process or large leakage current was observed. Hence, how to improve this issue has become an important task in this field.

SUMMARY OF THE INVENTION

According to an embodiment of the present invention, a method for fabricating semiconductor device includes the steps of: providing a substrate having a first region and a second region; forming a first fin-shaped structure on the first region; forming a shallow trench isolation (STI) around the first fin-shaped structure; forming a first oxide layer on the first fin-shaped structure; and forming a second oxide layer on the first oxide layer and the STI.

According to another aspect of the present invention, a semiconductor device includes: a substrate having a first region and a second region; a first fin-shaped structure on the first region; a shallow trench isolation (STI) around the first fin-shaped structure; a first oxide layer on the first fin-shaped structure; and a second oxide layer on the first oxide layer and the STI.

These and other objectives of the present invention will no doubt become obvious to those of ordinary skill in the art after reading the following detailed description of the preferred embodiment that is illustrated in the various figures and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1-4** illustrate a method for fabricating semiconductor device according to an embodiment of the present invention.

DETAILED DESCRIPTION

Referring to FIGS. **1-4**, FIGS. **1-4** illustrate a method for fabricating semiconductor device according to an embodiment of the present invention. As shown in FIG. **1**, a substrate **12** is first provided and a first region **14** and a second region **16** are defined on the substrate **12**. In this embodiment, the substrate **12** could be a semiconductor substrate including but not limited to for example a silicon substrate, an epitaxial substrate, a SiC substrate, or a silicon-on-insulator (SOI) substrate. Preferably, the first region **14** defined on the substrate **12** pertains to be an input and output (I/O) region, in which circuits will be formed in this region to connect core devices to external devices in the later process. The second region **16** on the other hand defines a core region, in which active devices including but not limited to for example metal-oxide semiconductor (MOS) transistors will be formed on this region in the later process.

Next, fin-shaped structure **18** is formed on the first region **14** and fin-shaped structures **20** are formed on the second region **16**. It should be noted that even though a single fin-shaped structure **18** is formed on the first region **14** while two fin-shaped structures **20** are formed on the second region **16**, the number or quantity of fin-shaped structures formed on each region is not limited to the ones disclose in this embodiment. Moreover, the fin-shaped structure **18** formed on the first region **14** or I/O region preferably includes greater width and/or greater size while the fin-shaped structures **20** disposed on the second region **16** or core region preferably includes smaller width and/or size.

According to an embodiment of the present invention, the fin-shaped structures **18** and **20** could be obtained by a sidewall image transfer (SIT) process. For instance, a layout pattern is first input into a computer system and is modified through suitable calculation. The modified layout is then defined in a mask and further transferred to a layer of sacrificial layer on a substrate through a photolithographic and an etching process. In this way, several sacrificial layers distributed with a same spacing and of a same width are formed on a substrate. Each of the sacrificial layers may be stripe-shaped. Subsequently, a deposition process and an etching process are carried out such that spacers are formed on the sidewalls of the patterned sacrificial layers. In a next step, sacrificial layers can be removed completely by performing an etching process. Through the etching process, the pattern defined by the spacers can be transferred into the substrate underneath, and through additional fin cut processes, desirable pattern structures, such as stripe patterned fin-shaped structures could be obtained.

Alternatively, the fin-shaped structures **18** and **20** could also be obtained by first forming a patterned mask (not shown) on the substrate, **12**, and through an etching process, the pattern of the patterned mask is transferred to the substrate **12** to form the fin-shaped structure **18** and **20**. Moreover, the formation of the fin-shaped structures **18** and **20** could also be accomplished by first forming a patterned hard mask (not shown) on the substrate **12**, and a semiconductor layer composed of silicon germanium is grown from the substrate **12** through exposed patterned hard mask via selective epitaxial growth process to form the corresponding

fin-shaped structure. These approaches for forming fin-shaped structures **18** and **20** are all within the scope of the present invention.

Next, a shallow trench isolation (STI) **22** is formed around the fin-shaped structures **18** and **20** on both first region **14** and second region **16**. Preferably the formation of the STI **22** could be accomplished by sequentially forming a first liner **24** on the substrate **12** and the fin-shaped structures **18**, **20** on the first region **14** and second region **16**, forming a second liner **26** on the first liner **24**, and a dielectric layer **28** on the second liner **26**.

In this embodiment, the dielectric layer **28** preferably includes dielectric material such as but not limited to for example silicon oxide. Preferably, the first liner **24** and the second liner **26** are made of same material such as silicon oxide in this embodiment, or the two liners **24** and **26** could also include dielectric material including but not limited to for example silicon nitride, silicon oxynitride (SiON), or oxide-nitride-oxide (ONO). Nevertheless, according to an embodiment of the present invention, the first liner **24** and the second liner **26** could also be made of different material including but not limited to for example silicon oxide, silicon nitride, silicon oxynitride (SiON), oxide-nitride-oxide (ONO), or combination thereof, which are all within the scope of the present invention.

In this embodiment, the first liner **24** is preferably formed by an in-situ steam generation (ISSG) process and the second liner **26** is preferably formed by an atomic layer deposition (ALD) process. Next, an etching back process or a combination of chemical mechanical polishing (CMP) process and etching back could be conducted to remove part of the dielectric layer **28**, part of the second liner **26** and part of the first liner **24** to forma STI **22** around the fin-shaped structures **18**, **20** on both first region **14** and second region **16**. Preferably, the first liner **24** and the second liner **26** share equal thickness, in which the thickness of the first liner **24** is between 25-30 Angstroms and the second liner **26** is also between 25-30 Angstroms, and the top surface of the STI **22** is slightly lower than the top surface of the fin-shaped structures **18**, **20**.

Next, as shown in FIG. **2**, an in-situ steam generation (ISSG) process is conducted to forma first oxide layer (or more specifically a silicon oxide layer) **30** on the fin-shaped structures **18**, **20** on both first region **14** and second region **16**, in which the first oxide layer **30** preferably covers the fin-shaped structures **18**, **20** protruding above the STI **22**, including the top surface and part of the sidewalls of the fin-shaped structures **18**, **20** but not extending to the top surface of the STI **22**. In this embodiment, the thickness of the first oxide layer **30** is less than the thickness of either one of the first liner **24** and the second liner **26**, and the thickness of the first oxide layer **30** is preferably between 7-15 Angstroms.

Next, an atomic layer deposition (ALD) process is conducted to form a second oxide layer (or more specifically a silicon oxide layer) **32** on the first oxide layer **30** and the STI **22**, in which the second oxide layer **32** is deposited to cover the first oxide layer **30** entirely and also extending to cover the surface of the STI **22** on both first region **14** and second region **16**. It should be noted that even though the second oxide layer **32** is preferably made of silicon oxide, according to an embodiment of the present invention, the second oxide layer could also include dielectric material including but not limited to for example a high-k dielectric layer or a silicon nitride layer.

According to an embodiment of the present invention, if the second oxide layer **32** or namely a dielectric layer were made of a high-k dielectric material, the high-k dielectric material could include a high-k dielectric layer having dielectric constant (k value) larger than 4. For instance, the high-k dielectric layer may be selected from hafnium oxide (HfO_2), hafnium silicon oxide ($HfSiO_4$), hafnium silicon oxynitride (HfSiON), aluminum oxide (Al_2O_3), lanthanum oxide (La_2O_3), tantalum oxide (Ta_2O_5), yttrium oxide (Y_2O_3), zirconium oxide (ZrO_2), strontium titanate oxide ($SrTiO_3$), zirconium silicon oxide ($ZrSiO_4$), hafnium zirconium oxide ($HfZrO_4$), strontium bismuth tantalate ($SrBi_2Ta_2O_9$, SBT), lead zirconate titanate ($PbZr_xTi_{1-x}O_3$, PZT), barium strontium titanate ($Ba_xSr_{1-x}TiO_3$, BST) or a combination thereof.

Preferably, the thickness of the second oxide layer **32** is greater than the thickness of the first oxide layer **30** and the combined thickness of the first oxide layer **30** and the second oxide layer **32** is approximately equal to the thickness of the first liner **24** alone or the second liner **26** alone, or approximate at 30 Angstroms.

Next, as shown in FIG. **3**, a patterned mask **34**, such as a patterned resist is formed on the first region **14**, and an etching process is conducted to completely remove the second oxide layer **32** and the first oxide layer **30** on the second region **16** to expose the fin-shaped structures **20** underneath.

Next, as shown in FIG. **4**, after exposing the fin-shaped structures **20** on the second region **16**, a chemical oxidation process is conducted by immersing or treating the fin-shaped structures **20** on the second region **16** with agent including but not limited to for example hydrogen peroxide (H_2O_2) and/or ammonia to form a thin oxide layer or third oxide layer **36** (or more specifically a silicon oxide layer) on the fin-shaped structures **20** on second region **16**. Similar to the first oxide layer **30** formed on the first region **14**, the third oxide layer **36** is also formed on the top surface and part of the sidewalls of the fin-shaped structures **20** protruding above the STI **22** without extending to cover the surface of the STI **22**.

Preferably, the thickness of the third oxide layer **36** formed on the second region **16** is less than the thickness of the first oxide layer **30** on the first region **14**, in which the thickness of the third oxide layer **36** in this embodiment is preferably between 3-14 Angstroms and most preferably at 7 Angstroms.

After the third oxide layer **36** is formed, a gate material layer (not shown) preferably made of material such as but not limited to for example polysilicon is formed on the first region **14** and second region **16**, and a photo-etching process is conducted to pattern the gate material layer for forming gate structures on the fin-shaped structure **18** on the first region **14** and fin-shaped structures **20** on the second region **16** respectively. Next, FinFET process could be carried out to form elements such as spacers around the gate structure and source/drain regions in the fin-shaped structure adjacent two sides of the spacer. Since the fabrication of a FinFET device is well known to those skilled in the art, the details of which are not explained herein for the sake of brevity.

Referring again to FIG. **4**, FIG. **4** further illustrates a structural view of a semiconductor device according to an embodiment of the present invention. As shown in FIG. **4**, the semiconductor preferably includes a substrate **12** having a first region **14** and a second region **16**, a fin-shaped structure **18** disposed on the first region **14**, fin-shaped structures **20** disposed on the second region **16**, a STI **22** around the fin-shaped structures **18**, **20**, a first oxide layer **30** and a second oxide layer **32** disposed on the fin-shaped

structure **18** on the first region **14**, and a third oxide layer **36** disposed on the fin-shaped structures **20** on the second region **16**.

In this embodiment, the first oxide layer **30** is disposed only on the fin-shaped structure **18** protruding above the STI **22** without extending to cover the surface of the STI **22**, the second oxide layer **32** is disposed on the first oxide layer **30** while covering the STI **22**, and the third oxide layer **36** is disposed only on the fin-shaped structures **20** protruding above the STI **22** without extending to the surface of the adjacent STI **22**.

Preferably, the STI **22** includes a first liner **24** on the substrate **12** and part of the sidewalls of the fin-shaped structures **18**, **20**, a second liner **26** on the first liner **24**, and a dielectric layer **28** on the second liner **26**. The first liner **24**, the second liner **26**, and the dielectric layer **28** could all include dielectric material such as but not limited to for example silicon oxide.

In this embodiment, the thickness of the first liner **24** is substantially the same as the thickness of the second liner **26**, the thickness of the first liner **24** is greater than the thickness of the first oxide layer **30**, the thickness of the second oxide layer **32** is slightly greater than the thickness of the first oxide layer **30**, the thickness of the first oxide layer **30** is greater than the thickness of the third oxide layer **36**, and the thickness of either the first liner **24** alone or the second liner **26** alone is substantially equal to a combined thickness of the first oxide layer **30** and the second oxide layer **32**.

Overall, the present invention first conducts an ISSG process to form a first oxide layer **30** preferably on the fin-shaped structure **18** on an I/O region (or the aforementioned first region **14**) and then conducts an ALD process to form a second oxide layer **32** on the first oxide layer **30**, in which the first oxide layer **30** and the second oxide layer **32** together serving as a gate dielectric layer for the device on the I/O region.

In contrast to the convention approach of carrying out only an ISSG process or only an ALD process to form a single oxide layer on the fin-shaped structure on the I/O region, the present invention takes the advantage of both processes by sequentially performing an ISSG process and an ALD process to form two consecutive oxide layers on the fin-shaped structure. This eliminates the drawbacks of overly consuming silicon substrate thereby shrinking the critical dimension (CD) of the fin width and improves leakage current substantially.

Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.

What is claimed is:

1. A semiconductor device, comprising:
- a substrate having a first region and a second region;
- a first fin-shaped structure on the first region and a second fin-shaped structure on the second region;
- a shallow trench isolation (STI) around the first fin-shaped structure and the second fin-shaped structure;
- a first oxide layer on the first fin-shaped structure;
- a second oxide layer on and directly contacting the first oxide layer and the STI; and
- a third oxide layer on the second fin-shaped structure having a width less than a width of the first fin-shaped structure, wherein a thickness of the third oxide layer is less than a thickness of the first oxide layer and different from a thickness of the second oxide layer and the thickness of the first oxide layer on the first region is less than the thickness of the second oxide layer on the first region.

2. The semiconductor device of claim **1**, wherein a thickness of the first oxide layer is less than a thickness of the second oxide layer.

3. The semiconductor device of claim **1**, further comprising:
- a first liner on the first fin-shaped structure;
- a second liner on the first liner; and
- a dielectric layer on the second liner and around the first fin-shaped structure.

4. The semiconductor device of claim **3**, wherein the first liner and the second liner comprise silicon oxide.

5. The semiconductor device of claim **3**, wherein a thickness of the first liner is greater than a thickness of the first oxide layer.

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