US011837497B2

(12) **United States Patent**
Wang

(10) **Patent No.: US 11,837,497 B2**
(45) **Date of Patent: Dec. 5, 2023**

(54) **SEMICONDUCTOR DEVICE**

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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 146 days.

(21) Appl. No.: **17/447,349**

(22) Filed: **Sep. 10, 2021**

(65) **Prior Publication Data**

US 2021/0407846 A1 Dec. 30, 2021

Related U.S. Application Data

(62) Division of application No. 16/747,699, filed on Jan. 21, 2020, now Pat. No. 11,158,532.

(30) **Foreign Application Priority Data**

Jan. 31, 2019 (CN) 201910097624.2

(51) **Int. Cl.**

H01L 21/762	(2006.01)
H01L 21/02	(2006.01)
H01L 21/8234	(2006.01)
H01L 21/033	(2006.01)

(52) **U.S. Cl.**
CPC .. ***H01L 21/76224*** (2013.01); ***H01L 21/02381*** (2013.01); ***H01L 21/0337*** (2013.01); ***H01L 21/7624*** (2013.01); ***H01L 21/823481*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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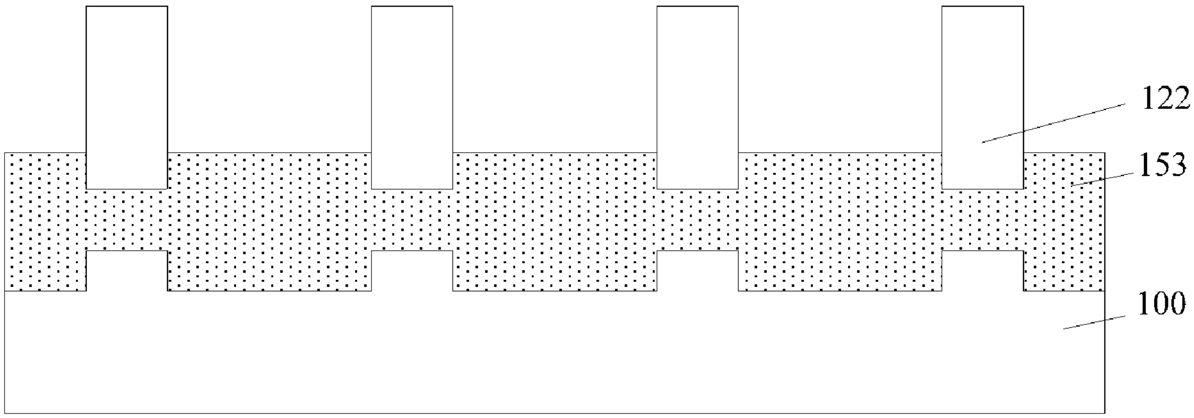
(57) **ABSTRACT**

The present disclosure provides a semiconductor device. The semiconductor device includes a substrate, including a plurality of protrusions; a plurality of fins formed over the substrate and aligned with the plurality of protrusions; and an isolation structure formed on the substrate and between the protrusions and the fins. An orthographic projection of each of the plurality of fins and an orthographic projection of a corresponding protrusion of the plurality of protrusions on the substrate coincide with each other.

7 Claims, 5 Drawing Sheets



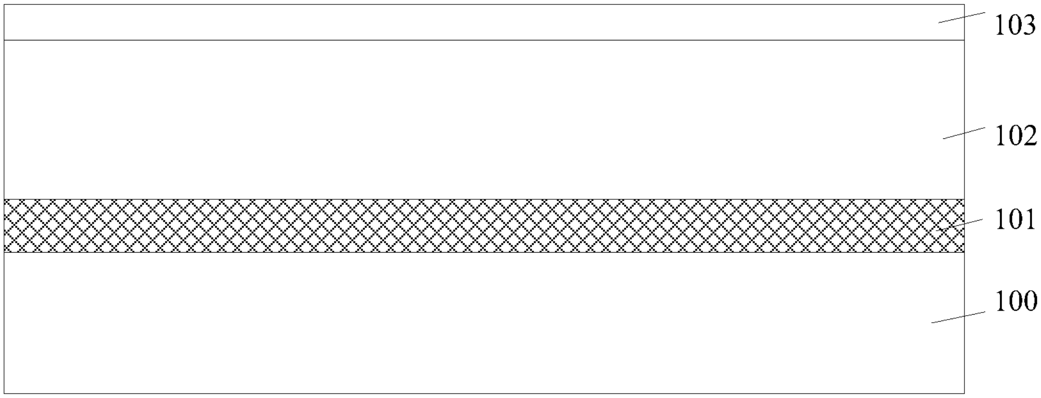


FIG. 1

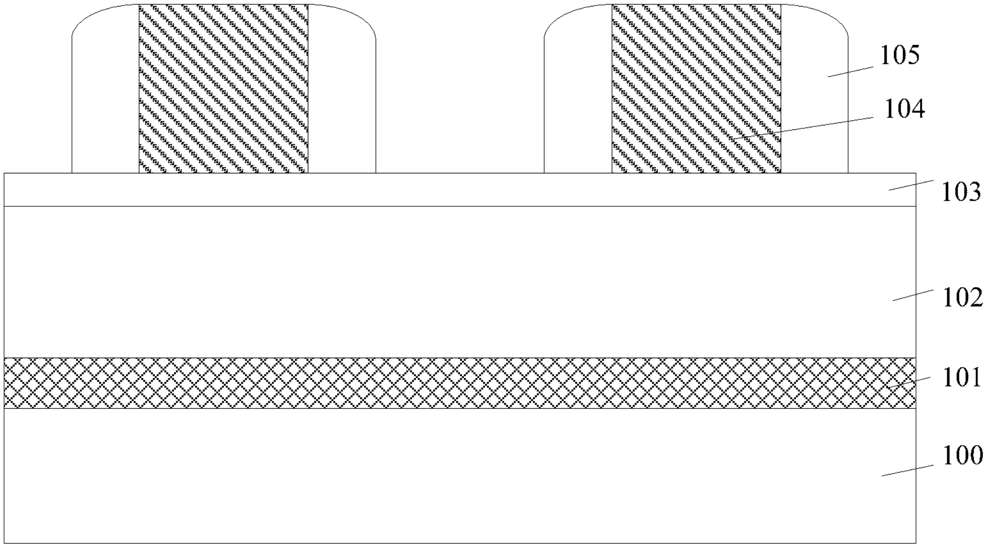


FIG. 2

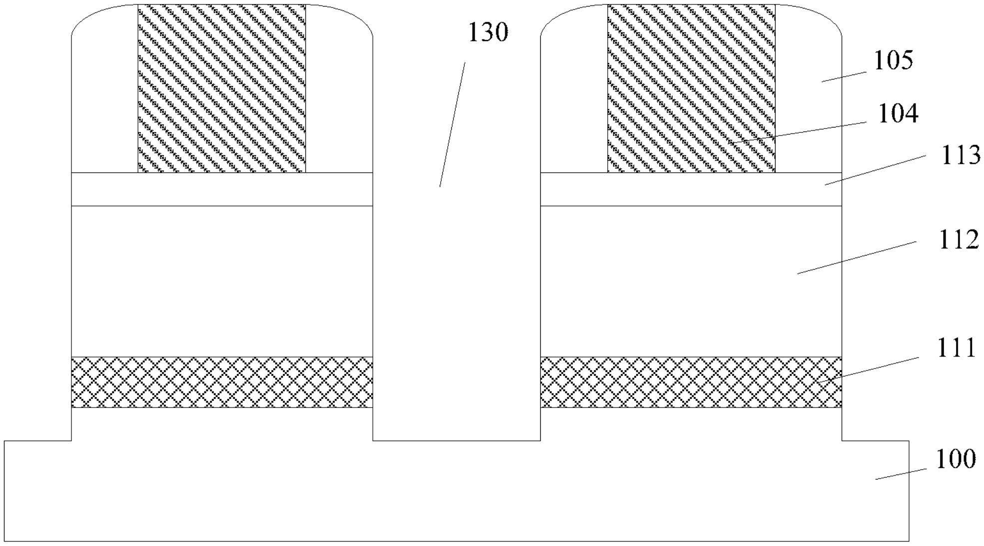


FIG. 3

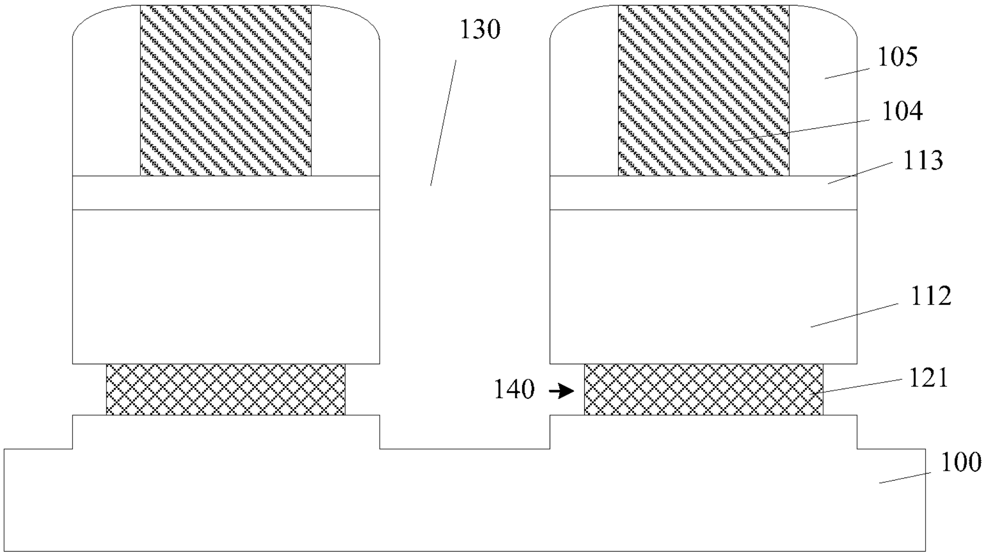


FIG. 4

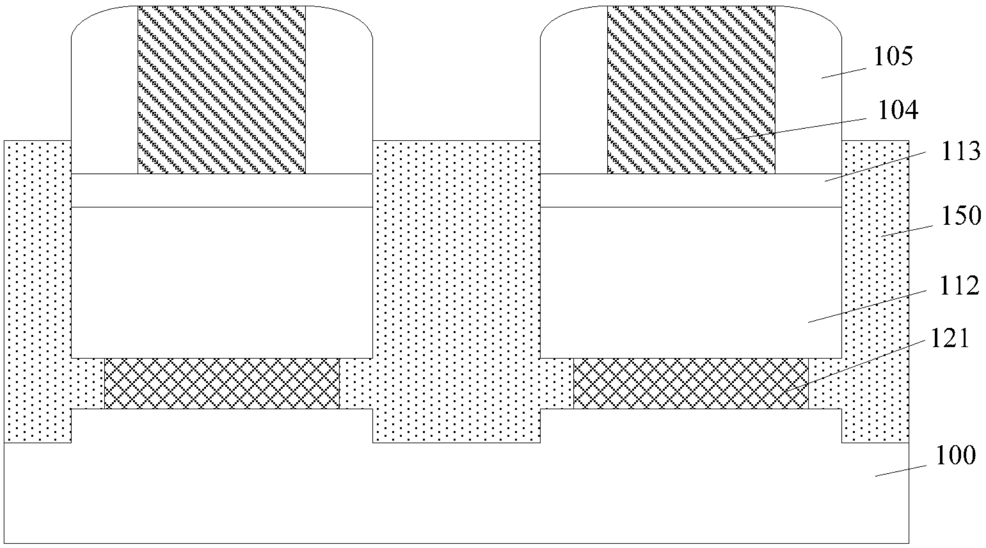


FIG. 5

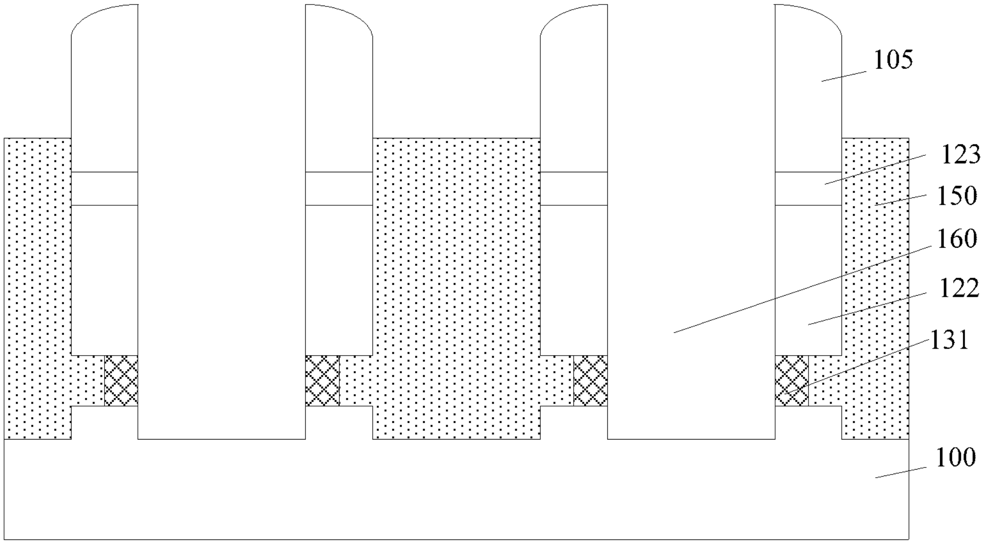


FIG. 6

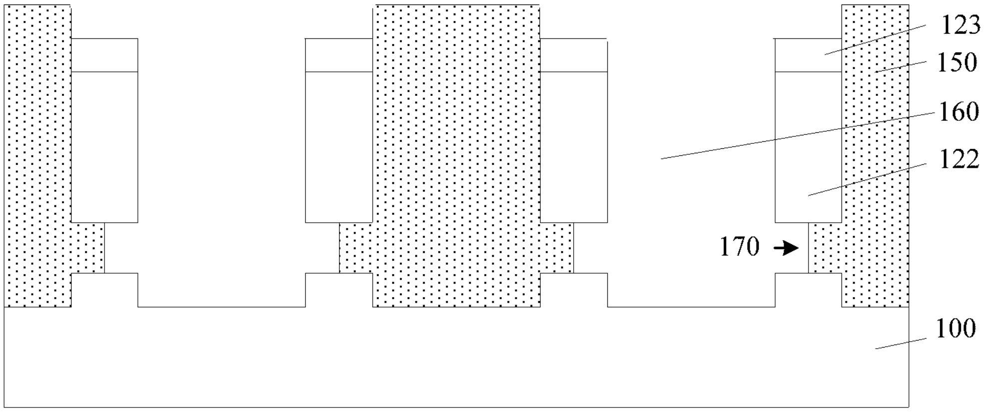


FIG. 7

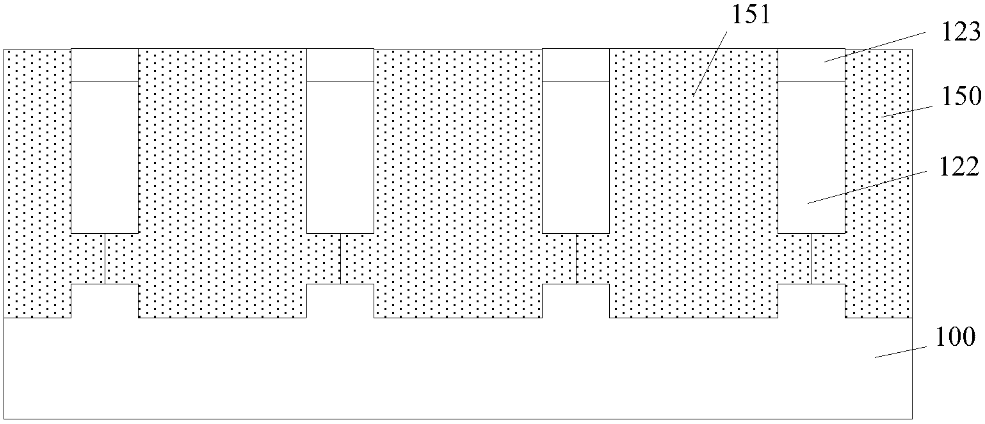


FIG. 8

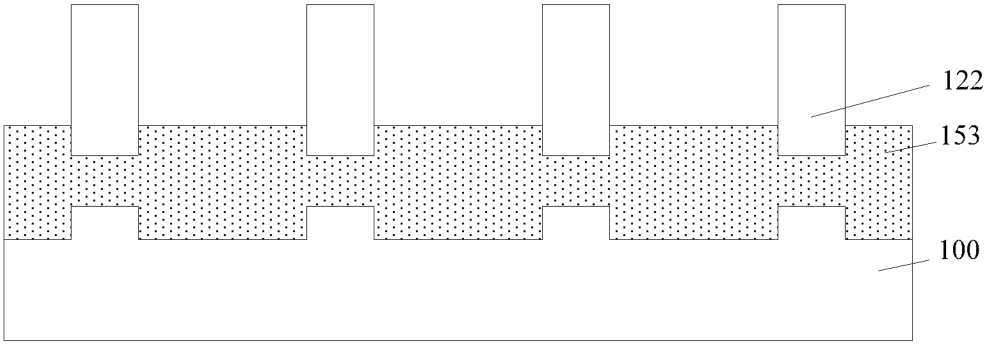


FIG. 9

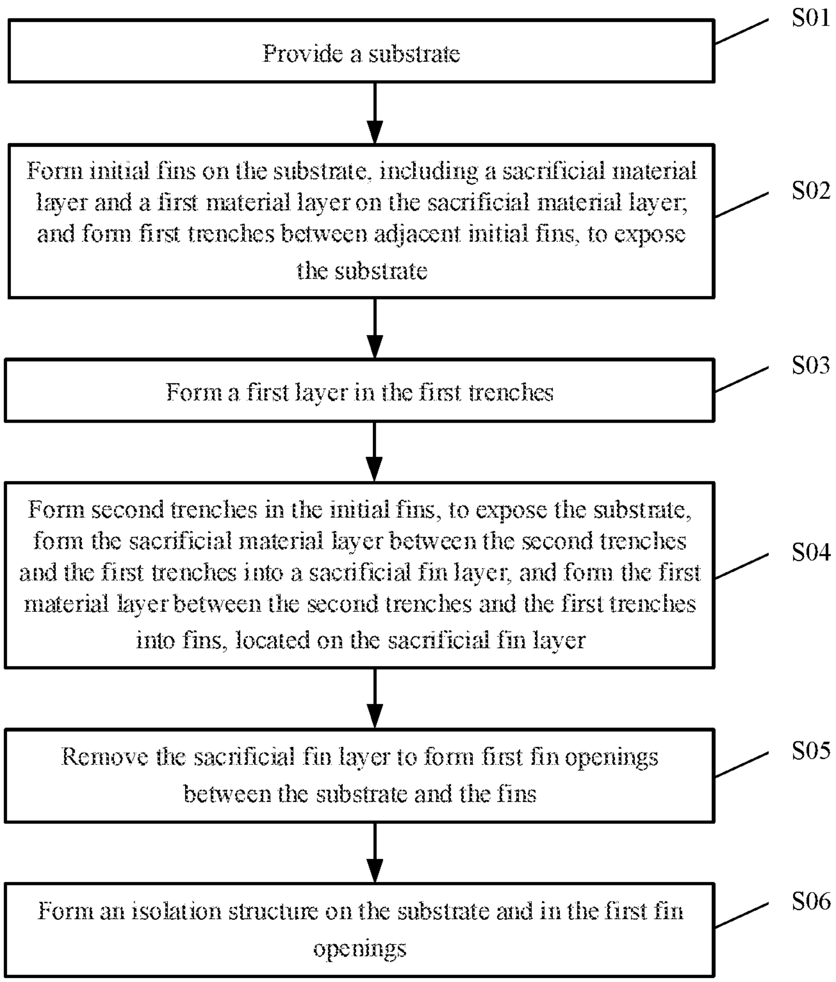

S01
Provide a substrate
S02
Form initial fins on the substrate, including a sacrificial material layer and a first material layer on the sacrificial material layer; and form first trenches between adjacent initial fins, to expose the substrate
S03
Form a first layer in the first trenches
S04
Form second trenches in the initial fins, to expose the substrate, form the sacrificial material layer between the second trenches and the first trenches into a sacrificial fin layer, and form the first material layer between the second trenches and the first trenches into fins, located on the sacrificial fin layer
S05
Remove the sacrificial fin layer to form first fin openings between the substrate and the fins
S06
Form an isolation structure on the substrate and in the first fin openings

FIG. 10

SEMICONDUCTOR DEVICE

CROSS-REFERENCES TO RELATED APPLICATION

This application is a divisional application of U.S. patent application Ser. No. 16/747,699, filed on Jan. 21, 2020, which claims the priority of Chinese Patent Application No. 201910097624.2, filed on Jan. 31, 2019, the content of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

The present disclosure generally relates to the field of semiconductor manufacturing and, in particular, to a semiconductor device and a fabrication method thereof.

BACKGROUND

With rapid development of semiconductor manufacturing technologies, semiconductor devices are moving in a direction toward higher component densities and higher integration. Semiconductor devices, as the most basic devices, are widely used. A traditional planar device has weak control of a channel current, resulting in short-channel effects and a leakage current, which ultimately affects electrical performance of a semiconductor device.

To overcome the short-channel effects of a device and suppress the leakage current, a conventional method proposes a fin field effect transistor (Fin FET), which is a common multi-gate device, and structures of the Fin FET include fins and an isolation layer on a surface of a semiconductor substrate, that the isolation layer covers a portion of sidewalls of the fins, and a surface of the isolation layer is lower than a top of the fins; gate structures on the surface of the isolation layer, and the top and the side walls of the fins; and source and drain regions in the fins on both sides of the gate structures. The gate structures of the Fin FET has a weak control ability on the fins covered by the isolation structure, especially a bottom of the fins covered by the isolation structure, and a leakage current of an off state of the semiconductor device is difficult to control. To reduce the leakage current of the off state of the Fin FET, SOI (Silicon-On-Insulator) technology can be used.

However, there is a need to improve performance of the semiconductor device fabricated by the conventional methods.

SUMMARY

One aspect of the present disclosure provides a fabrication method of a semiconductor device, including: providing a substrate; forming initial fins on the substrate, that the initial fins include a sacrificial material layer and a first material layer on a surface of the sacrificial material layer, first trenches are formed between adjacent initial fins, and a bottom of the first trenches exposes the substrate; forming a first layer in the first trenches; forming second trenches in the initial fins, that a bottom of the second trenches exposes the substrate, the sacrificial material layer between the second trenches and the first trenches is formed into a sacrificial fin layer, the first material layer between the second trenches and the first trenches is formed into fins, and the fins are located on a surface of the sacrificial fin layer; removing the sacrificial fin layer to form first fin openings between the substrate and the fins; and forming an isolation structure on the substrate and in the first fin openings.

Another aspect of the present disclosure provides a semiconductor device, including: a substrate, including protrusions; fins formed over the substrate and aligned with the protrusions, wherein orthographic projections of a fin and a protrusion on the substrate coincide with each other; and an isolation structure, formed on the substrate and between the protrusions and the fins.

Other aspects or embodiments of the present disclosure can be understood by those skilled in the art in light of the description, the claims, and the drawings of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The following drawings are merely examples for illustrative purposes according to various disclosed embodiments and are not intended to limit the scope of the present disclosure.

FIGS. **1** to **9** illustrate structures corresponding to certain stages during an exemplary fabrication process of a semiconductor device consistent with various disclosed embodiments of the present disclosure; and

FIG. **10** illustrates an exemplary fabrication process of a semiconductor device consistent with various disclosed embodiments of the present disclosure.

DETAILED DESCRIPTION

A semiconductor device is often formed by: providing a SOT substrate, that the SOI substrate includes a silicon substrate, an insulating oxide layer on a surface of the silicon substrate, and a monocrystalline silicon layer on a surface of the insulating oxide layer; and etching the monocrystalline silicon layer on the SOI to form fins.

The conventional method for fabricating the SOI substrate is to implant a buried oxide layer in the silicon substrate, which is a complicated process and has high costs, thereby restricting development of the semiconductor device on the SOI substrate.

In a fabricating method provided by the present disclosure, by forming initial fins on a substrate, that the initial fins include a sacrificial material layer and a first material layer on a surface of the sacrificial material layer; forming second trenches in the initial fins to form fins and a sacrificial fin layer; removing the sacrificial fin layer to form first fin openings between the substrate and the fins; and forming an isolation structure on the substrate and in the first fin openings, a silicon semiconductor device on an insulating substrate is fabricated. The method improves the performance of the semiconductor device.

The above described objects, features and advantages of the present disclosure may become easier to be understood from the embodiments of the present disclosure described in detail below with reference to the accompanying drawings.

FIGS. **1** to **9** illustrate structures corresponding to certain stages during an exemplary fabrication process of a semiconductor device consistent with various disclosed embodiments of the present disclosure.

FIG. **10** illustrates an exemplary fabrication process of a semiconductor device consistent with various disclosed embodiments of the present disclosure.

Referring to FIG. **1** and FIG. **10**, a substrate **100** is provided (**S01**).

The substrate **100** is made of monocrystalline silicon. The substrate **100** may also be made of one of polysilicon and amorphous silicon. The substrate **100** may also be made of a semiconductor material such as one of germanium, silicon germanium, gallium arsenide, and the like.

In one embodiment, the substrate **100** is made of monocrystalline silicon.

An initial sacrificial material layer **101** is formed on the substrate **100**, and the initial sacrificial material layer **101** and the substrate **100** are made of different materials.

The initial sacrificial material layer **101** is made of silicon germanium. The initial sacrificial material layer **101** may also be made of a semiconductor material such as one of germanium, silicon germanium, gallium arsenide, and the like.

The initial sacrificial material layer **101** provides a space for subsequent formation of first fin openings.

In one embodiment, the initial sacrificial material layer **101** is made of silicon germanium.

An initial first material layer **102** is formed on the initial sacrificial material layer **101**, and the initial first material layer **102** and the initial sacrificial material layer **101** are made of different materials.

The initial first material layer **102** is made of monocrystalline silicon. The initial first material layer **102** may also be made of one of polysilicon and amorphous silicon. The initial first material layer **102** may also be made of a semiconductor material such as one of germanium, silicon germanium, gallium arsenide, and the like.

The initial first material layer **102** provides a material layer for subsequent formation of fins.

In one embodiment, the initial first material layer **102** and the substrate **100** are made of a same material. The initial first material layer **102** is made of monocrystalline silicon.

In other embodiments, the initial first material layer **102** and the substrate **100** may be made of different materials.

In one embodiment, the method further includes: forming an initial protective layer **103** on a surface of the initial first material layer **102**.

The initial protective layer **103** provides a material layer for subsequent formation of a protective layer.

The initial first material layer **102** and the initial sacrificial material layer **101** are etched to form initial fins with first trenches between adjacent initial fins, that a bottom of the first trenches exposes the substrate **100**.

Referring to FIG. **2**, a first auxiliary pattern layer **104** is formed on the initial first material layer **102**, that the first auxiliary pattern layer **104** covers a portion of a surface of the initial first material layer **102**. A first mask layer **105** is formed on sidewalls of the first auxiliary pattern layer **104**.

The first auxiliary pattern layer **104** provides assistance for forming the first mask layer **105**, and the first auxiliary pattern layer **104** and the first mask layer **105** determine positions and shapes of the initial fins that are subsequently formed.

A distance between adjacent first auxiliary pattern layers **104** is equal.

A method for forming the first auxiliary pattern layer **104** includes: forming a first auxiliary pattern film (not shown) on the initial first material layer **102**; forming a first pattern layer (not shown) on a surface of the first auxiliary pattern film, that the first pattern layer exposes a portion of a surface of the first auxiliary pattern film; and etching the first auxiliary pattern film by using the first pattern layer as a mask until a surface of the initial first material **102** is exposed, to form the first auxiliary pattern layer **104** on the surface of the initial first material layer **102**.

In one embodiment, a first auxiliary pattern film is formed on a surface of the initial protection layer **103**. The first auxiliary pattern film is etched by using a first pattern layer as a mask until a surface of the initial protection layer **103** is exposed, to form the first auxiliary pattern layer **104** on the surface of the initial protective layer **103**.

The first auxiliary pattern layer **104** may be made of one of amorphous carbon and amorphous silicon.

In one embodiment, the first auxiliary pattern layer **104** is made of amorphous carbon.

A first mask layer **105** determines positions and shapes of the fins.

A method for forming the first mask layer **105** includes: forming an initial first mask layer (not shown) on a surface of the initial first material layer **102**, that the initial first mask layer covers a top and sidewalls of the first auxiliary pattern layer **104**; and etching back the initial first mask layer to expose the top of the first auxiliary pattern layer **104**, to form the first mask layer **105** on the sidewalls of the first auxiliary pattern layer **104**.

The first mask layer **105** may be made of one of silicon nitride, silicon oxide, silicon oxynitride, silicon borohydride, silicon oxynitride, and silicon oxynitride.

In one embodiment, the first mask layer **105** is made of silicon nitride.

In another embodiment, after a first mask layer is formed, a first auxiliary pattern layer is removed. A method for forming initial fins includes: after the first mask layer is formed, before the first auxiliary pattern layer is removed, by using the first auxiliary pattern layer and the first mask layer as masks, etching an initial first material layer and an initial sacrificial material layer to form the initial fins on a substrate, that first trenches are formed between adjacent initial fins, and a bottom of the first trenches exposes the substrate.

Referring to FIG. **3** and FIG. **10** (S**02**), after the first mask layer **105** is formed, the initial first material layer **102** and the initial sacrificial material layer **101** are etched by using the first auxiliary pattern layer **104** and the first mask layer **105** as masks, to form initial fins on the substrate, that first trenches **130** are formed between adjacent initial fins, and a bottom of the first trenches **130** exposes the substrate **100**.

The initial first material layer **102** and the initial sacrificial material layer **101** are etched such that the initial first material layer **102** is formed into a first material layer **112**, and the initial sacrificial material layer **101** is formed into a sacrificial material layer **111**. The initial fins include the sacrificial material layer **111** and the first material layer **112** on the sacrificial material layer **111**.

A thickness of the sacrificial material layer **111** is about 5 nm to about 100 nm.

The first trenches **130** expose sidewalls of the initial fins.

A process of etching the initial first material layer **102** and the initial sacrificial material layer **101** includes an anisotropic dry etching.

In one embodiment, the initial first material layer **102**, the initial sacrificial material layer **101**, and a portion of the substrate **100** are etched to form the initial fins.

Referring to FIG. **4**, after the initial fins are formed, a portion of the sacrificial material layer **111** of the initial fins exposed by the first trenches **130** is removed, to form second fin openings **140** into corresponding sidewalls of the first trenches **130** and, between the first material layer **112** and the substrate **100**.

The portion of the sacrificial material layer **111** of the initial fins exposed by the first trenches **130** is removed such that the sacrificial material layer **111** is formed into a first sacrificial layer **121**, and sidewalls of the first sacrificial layer **121** are recessed relative to the first material layer **112** of the initial fins.

The second fin openings **140** provide a space for subsequent formation of an isolation structure.

A process of removing a portion of the sacrificial material layer **111** of the initial fins exposed by the first trenches **130** is a wet etching process. A solution of the wet etching process for removing a portion of the sacrificial material layer **111** has a good selection ratio of silicon and silicon germanium, and can ensure that the silicon morphology is not affected while removing the silicon germanium. Parameters of the wet etching process for removing a portion of the sacrificial material layer **111** in one embodiment include: a HCl gas solution as an etching solution, a temperature between about 25 degrees Celsius to about 300 degrees Celsius, and a volume percentage of the HCl gas solution between about 20% to about 90%.

In one embodiment, the sacrificial material layer **111** is made of silicon, the first material layer **112** is made of silicon germanium, and an etching solution with MCI has a good selection ratio.

In another embodiment, second fin openings are not formed.

Referring to FIG. **5** and FIG. **10**, a first layer **150** is formed in the first trenches **130** (S**03**).

The first layer **150** is made of one of silicon oxide, silicon nitride, silicon oxynitride, silicon borohydride, silicon oxynitride, and silicon oxynitride.

In one embodiment, the first layer **150** is made of silicon oxide.

In one embodiment, the method further includes forming the first layer **150** in the second fin openings **140**.

A method of forming the first layer **150** includes: forming a first isolation film (not shown) on the substrate **100** and in the first trenches **130** to cover the initial fins; and etching back the first isolation film, to form the first layer **150**.

A process of forming the first isolation film is a deposition process such as a fluid chemical vapor deposition process. The first isolation film is formed by the fluid chemical vapor deposition process, so that filling performance of the first isolation film is better.

The first layer **150** provides a material layer for subsequent formation of an isolation structure.

A subsequent removal of a sacrificial fin layer **131** forms first tin openings between fins **122** and the substrate **100**, and the first layer **150** supports the fins **122**.

In another embodiment, a first layer serves as a sacrificial layer, and the first layer is made of one of SiC and GaAs.

Referring to FIG. **6**, after the first layer **150** is formed, the first auxiliary pattern layer **104** is removed to expose a portion of a surface of the initial fins. Referring to FIG. **6**, after the first auxiliary pattern layer **104** is removed, the initial fins are etched by using the first mask layer **105** as a mask, to form second trenches **160** in the initial fins, that a bottom of the second trenches **160** exposes the substrate **100**. As such, the second trench **160** may pass through the first material layer **112** and first sacrificial layer **121** and into the substrate **100**, to form fins **122** (from the first material layer **112**) and a sacrificial fin layer **131** (from the first sacrificial layer **121**). The fins **122** are formed on the sacrificial fin layer **131** (S**04**).

The second trenches **160** expose sidewalls of the fins **122**. The sacrificial fin layer **131** is located between the substrate **100** and the fins **122**.

In another embodiment, second fin openings may not be formed, second trenches are formed in initial fins, a bottom of the second trenches exposes the substrate, such that a sacrificial material layer between the second trenches and first trenches is formed into a sacrificial fin layer, and a first material layer between the second trenches and the first trenches is formed into fins that are on a surface of the sacrificial fin layer.

A process of etching the first material layer **112** of the initial fins and the first sacrificial layer **121** of the initial fins includes an anisotropic dry etching.

In another embodiment, a method of forming second trenches includes: after a first layer is formed, forming a second mask layer on a surface of initial fins, that the second mask layer exposes a portion of the surface of the initial fins; and etching the initial fins by using the second mask layer as a mask to form the second trenches on a substrate.

Referring to FIG. **7** and FIG. **10**, after the second trenches **160** are formed, the sacrificial fin layer **131** is removed to form first fin openings **170** (S**05**).

Alternatively, the sacrificial fin layer **131** exposed by the second trenches **160** is removed to form the first fin openings **170**.

The first fin openings **170** provide a space for subsequent formation of an isolation structure.

In one embodiment, after the sacrificial fin layer **131** is removed, the method further includes: removing the first mask layer **105** at a top of the fins **122**.

After the first mask layer **105** on the top of the fins **122** is removed, a protective layer **123** on the top of the fins **122** is exposed.

In other embodiments, the first mask layer on the top of the fins **122** is removed before the sacrificial fin layer **131** is removed.

Referring to FIG. **10**, the isolation structure is formed on the substrate **100** and in the first fin openings **170** (S**06**).

In one embodiment, the isolation structure covers a portion of sidewalls of the fins **122**.

Referring to FIG. **8**, after the fins **122** are formed and the first mask layer **105** is removed, a first isolation layer **151** is formed in the second trenches **160** and in the first fin openings **170**.

A method of forming the first isolation layer **151** includes: forming a second isolation film (not shown) on the substrate **100**, in the second trenches **160**, and in the first fin openings **170**, to cover the fins **122**; and planarizing the second isolation film until a top of the fins **122** is exposed to form the first isolation layer **151**.

In one embodiment, the first isolation layer **151** exposes a surface of the protective layer **123**.

A process of forming a second isolation film is a deposition process such as a fluid chemical vapor deposition process. A second isolation film formed by the fluid chemical vapor deposition process has better filling performance.

The first isolation layer **151** provides a material layer for subsequently forming an isolation structure.

Referring to FIG. **9**, after the first isolation layer **151** is formed, the first layer and the first isolation layer **151** are etched back to form an isolation structure **153**, that the isolation structure **153** covers a portion of the sidewalls of the fins **122**, and the isolation structure **153** fills the first fin openings **170**.

A top surface of the isolation structure **153** is higher than a bottom surface of the fins **122**.

The isolation stricture **153** is formed between the fins **122** and the substrate **100**. The fins **122**, the isolation structure **153**, and the substrate **100** form a silicon structure on an insulating substrate. The silicon structure on the insulating substrate is formed on a conventional single-material substrate; therefore cost is low, because a single-material substrate is inexpensive. Moreover, the silicon structure on the insulating substrate is well integrated with other processes.

In another embodiment, a first layer is used as a sacrificial layer, and a method for forming an isolation structure includes: after fins are formed, forming a first isolation layer in second trenches and first fin openings; after the first isolation layer is formed, removing the first layer, exposing first trenches, and forming a second isolation layer in the first trenches; after the second isolation layer is formed, etching back the second isolation layer and the first isolation layer to form the isolation structure.

Correspondingly, one embodiment further provides a semiconductor device formed by the above method. Referring to FIG. **9**, the semiconductor device includes: a substrate **100**; fins **122** on the substrate **100**, that first fin openings are formed between the fins **122** and the substrate **100**; and an isolation structure **153** on the substrate **100**, that the isolation structure **153** covers a portion of sidewall of the fins **122**, and the isolation structure **153** fills the first fin openings.

Compared to the conventional fabrication methods, the technical solution of embodiments of the present disclosure has the following beneficial effects.

In the fabrication method of a semiconductor device provided by the present disclosure, a first layer is formed in first trenches, and the first layer supports fins after removing a sacrificial fin layer. First fin openings are located between a substrate and the fins, and an isolation structure is formed on the substrate and in the first fin openings. Having the isolation structure between the fins and the substrate, the fins, the isolation structure, and the substrate form a silicon structure on an insulating substrate. The silicon structure on the insulating substrate is formed on a conventional single-material substrate, therefore cost is low, because a single-material substrate is inexpensive. Moreover, the silicon structure on the insulating substrate is well integrated with other processes.

The embodiments disclosed herein are exemplary only. Other applications, advantages, alternations, modifications, or equivalents to the disclosed embodiments that are obvious to those skilled in the art are intended to be encompassed within the scope of the present disclosure.

What is claimed is:

1. A semiconductor device, comprising:

a substrate, including a plurality of protrusions;

a plurality of fins formed over the substrate and aligned with the plurality of protrusions, wherein an orthographic projection of each of the plurality of fins and an orthographic projection of a corresponding protrusion of the plurality of protrusions on the substrate coincide with each other; and

an isolation structure, formed on the substrate and between the protrusions and the fins;

wherein a top surface of the isolation structure is higher than a bottom surface of each of the plurality of fins.

2. The device according to claim **1**, wherein:

the substrate is made of monocrystalline silicon.

3. The device according to claim **1**, wherein:

the isolation structure is made of one of silicon oxide, silicon nitride, silicon oxynitride, silicon borohydride, silicon oxynitride, and silicon oxynitride.

4. The device according to claim **1**, wherein:

a thickness of a portion of the isolation structure between each of the plurality of fins and the corresponding protrusion of the plurality of protrusions is about 5 nm to about 100 nm.

5. The device according to claim **1**, wherein:

the plurality of fins are made of a same material as the substrate.

6. The device according to claim **1**, wherein:

a top surface of each of the plurality of fins is higher than the top surface of the isolation structure.

7. The device according to claim **6**, wherein:

a bottom surface of the isolation structure is lower than a top surface of the corresponding protrusion of the plurality of protrusions.

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