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United States Patent	12396252
Kind Code	B2
Date of Patent	August 19, 2025
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Semiconductor structure and method for forming the same

Abstract

A semiconductor structure includes a substrate, a first FET device and a second FET device. The substrate has a first region and a second region. The first FET device is in the first region, and the second FET device is in the second region. The first FET device includes a first isolation structure, a first gate electrode disposed over a portion of the first isolation structure, and a first gate dielectric layer between the substrate and the first gate electrode. The first gate dielectric layer has a first thickness. The second FET device includes a plurality of fin structures, a plurality of second isolation structures, a second gate electrode over the plurality of fin structures, and a second gate dielectric layer between the second gate electrode and the plurality of fin structures. The second gate dielectric layer has a second thickness. The second thickness is less than the first thickness.

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Appl. No.: 17/824936

Filed: May 26, 2022

Prior Publication Data

Document Identifier	Publication Date
US 20230387110 A1	Nov. 30, 2023

Publication Classification

Int. Cl.: H10D84/83 (20250101); H10D64/01 (20250101); H10D84/01 (20250101); H10D84/03 (20250101)

U.S. Cl.:

CPC H10D84/834 (20250101); H10D64/017 (20250101); H10D84/0151 (20250101); H10D84/0158 (20250101); H10D84/038 (20250101);

Field of Classification Search

CPC: H10D (84/834); H10D (64/017); H10D (84/0151); H10D (84/0158); H10D (84/038); H10D (18/40); H10D (64/252); H10D (84/0107); H10D (1/694); H10D (1/66); H10D (30/797); H10D (64/514); H10D (84/0128); H10D (84/0144); H10D (84/0142); B65D (83/141); H10F (30/2863); A23B (2/783); A45C (11/003)

USPC: 257/392

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Background/Summary

BACKGROUND

- (1) The electronics industry is experienced an ever-increasing demand for smaller and faster electronic devices that are able to support greater numbers of increasingly complex and sophisticated functions. Accordingly, there is a continuing trend in the semiconductor industry to manufacture low-cost, high-performance, low-power integrated circuits (ICs). Thus far, such goals have been achieved in large part by scaling down semiconductor IC dimensions (e.g., minimum feature size) and thereby improving production efficiency and reducing associated costs. However, such downscaling has also introduced increased complexity to the semiconductor manufacturing process. Thus, the realization of continued advances in semiconductor ICs and devices requires similar advances in semiconductor manufacturing processes and technology.
- (2) As technology nodes achieve progressively smaller scales, in some IC designs, researchers seek to replace a typical polysilicon gate with a metal gate to improve device performance by decreasing feature sizes. One approach to forming the metal gate is called a “gate-last” approach, sometimes referred to as a replacement polysilicon gate (RPG) approach. In the RPG approach, the metal gate is fabricated last, which allows for a reduced number of subsequent operations.
- (3) Further, as the dimensions of a transistor decrease, a thickness of a gate dielectric layer may be reduced to maintain performance with a decreased gate length. In order to reduce gate leakage, a

high dielectric constant (high-k or HK) gate dielectric layer is used to provide a thickness as effective as that provided by a typical gate oxide used in larger technology nodes. A high-k metal gate (HKMG) approach including a metal gate electrode and the high-k gate dielectric layer is therefore recognized. However, the HKMG approach is a complicated approach, and many issues arise.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

- (1) Aspects of the present disclosure are best understood from the following detailed description when read with the accompanying figures. It should be noted that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.
- (2) FIG. 1 is a flowchart representing a method for forming a semiconductor structure according to aspects of the present disclosure.
- (3) FIGS. 2 to 14 are schematic drawings illustrating the semiconductor structure at various fabrication stages according to aspects of the present disclosure in one or more embodiments.
- (4) FIGS. 15A and 15B show different cross-sectional views of the semiconductor structure at a fabrication stage subsequent to that in FIG. 14.
- (5) FIGS. 16A and 16B are schematic drawings illustrating the semiconductor structure at a fabrication stage subsequent to that in FIGS. 15A and 15B.
- (6) FIG. 17 is a schematic drawing illustrating the semiconductor structure at a fabrication stage subsequent to that in FIG. 16A.
- (7) FIGS. 18A and 18B show different cross-sectional views of the semiconductor structure at a fabrication stage subsequent to that in FIG. 17.
- (8) FIGS. 19A and 19B are schematic drawings illustrating the semiconductor structure at a fabrication stage subsequent to that in FIGS. 18A and 18B.
- (9) FIGS. 20A and 20B are schematic drawings illustrating the semiconductor structure at a fabrication stage subsequent to that in FIGS. 19A and 19B.

DETAILED DESCRIPTION

- (10) The following disclosure provides many different embodiments, or examples, for implementing different features of the provided subject matter. Specific examples of elements and arrangements are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to be limiting. For example, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed between the first and second features, such that the first and second features may not be in direct contact. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed.
- (11) Further, spatially relative terms, such as “beneath,” “below,” “lower,” “above,” “upper,” “on” and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. The spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. The apparatus may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein may likewise be interpreted accordingly.
- (12) As used herein, the terms such as “first,” “second” and “third” describe various elements,

components, regions, layers and/or sections, but these elements, components, regions, layers and/or sections should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer or section from another. The terms such as “first,” “second” and “third” when used herein do not imply a sequence or order unless clearly indicated by the context.

(13) Notwithstanding that the numerical ranges and parameters setting forth the broad scope of the disclosure are approximations, the numerical values set forth in the specific examples are reported as precisely as possible. Any numerical value, however, inherently contains certain errors necessarily resulting from the standard deviation found in the respective testing measurements. Also, as used herein, the terms “substantially,” “approximately” or “about” generally mean within a value or range that can be contemplated by people having ordinary skill in the art. Alternatively, the terms “substantially,” “approximately” or “about” mean within an acceptable standard error of the mean when considered by one of ordinary skill in the art. People having ordinary skill in the art can understand that the acceptable standard error may vary according to different technologies.

(14) Other than in the operating/working examples, or unless otherwise expressly specified, all of the numerical ranges, amounts, values and percentages such as those for quantities of materials, durations of times, temperatures, operating conditions, ratios of amounts, and the likes thereof disclosed herein should be understood as modified in all instances by the terms “substantially,” “approximately” or “about.” Accordingly, unless indicated to the contrary, the numerical parameters set forth in the present disclosure and attached claims are approximations that can vary as desired. At the very least, each numerical parameter should at least be construed in light of the number of reported significant digits and by applying ordinary rounding techniques. Ranges can be expressed herein as from one endpoint to another endpoint or between two endpoints. All ranges disclosed herein are inclusive of the endpoints, unless specified otherwise.

(15) The fins may be patterned by any suitable method. For example, the fins may be patterned using one or more photolithography processes, including double-patterning or multi-patterning processes. Generally, double-patterning or multi-patterning processes combine photolithography and self-aligned processes, allowing patterns to be created that have, for example, pitches smaller than what is otherwise obtainable using a single, direct photolithography process. For example, in one embodiment, a sacrificial layer is formed over a substrate and patterned using a photolithography process. Spacers are formed alongside the patterned sacrificial layer using a self-aligned process. The sacrificial layer is then removed, and the remaining spacers may then be used to pattern the fins.

(16) With ongoing down-scaling of integrated circuits, power supply voltages of the circuits may be reduced. However, the voltage reduction may be different in different circuits or regions. For example, threshold voltage (V_t) requirements of memory circuits may be different from those of core circuits. A multiple- V_t capability is therefore desired for device design.

(17) However, integration of a multiple- V_t device in a FinFET device can raise some issues. In some comparative approaches, a ratio of a thicknesses of a gate dielectric layer of a high-voltage (HV) device to a thickness of a gate dielectric layer of a low-voltage (LV) device may range from approximately 3.0 to approximately 8. It is difficult to integrate the two gate dielectric layers having such different thicknesses. Further, the HV device may need an isolation structure of greater dimension. Such isolation structure may weaken or damage fin structures.

(18) Embodiments of a method for forming a semiconductor structure are therefore provided. The semiconductor structure is formed in an HKMG process in accordance with the embodiments. The semiconductor structure includes both a planar device and a non-planar device in some embodiments, for example but not limited to a FinFET device. In some embodiments, the method includes formation of isolation structures for an HV device prior to formation of an isolation structure for an LV FinFET device. In some embodiments, the method include formation of a gate dielectric layer for the HV device prior to formation of a gate dielectric layer for the LV FinFET device. In some embodiments, the method provides a boundary dummy between the HV device and

the LV FinFET device. According to the method, the issue of the gate dielectric layer and the issue of the depth of the isolation structures for the HV devices may be mitigated when integrating the formation of the HV device with the formation of the FinFET device.

(19) FIG. 1 is a flowchart representing a method for forming a semiconductor structure **10** according to aspects of the present disclosure. The method **10** includes a number of operations (**101**, **102**, **103**, **104**, **105** and **106**). The method **10** will be further described according to one or more embodiments. It should be noted that the operations of the method **10** may be rearranged or otherwise modified within the scope of the various aspects. It should be further noted that additional processes may be provided before, during, and after the method **10**, and that some other processes may just be briefly described herein. Thus, other implementations are possible within the scope of the various aspects described herein.

(20) FIGS. 2 to 20B are schematic drawings illustrating the semiconductor structure at various fabrication stages according to aspects of the present disclosure in one or more embodiments. Referring to FIG. 2, in some embodiments, in operation **101**, the method **10** includes receiving a substrate **202** having a first region **204a** and a second region **204b**, but the disclosure is not limited thereto. For example, in some embodiments, the substrate **202** may have a third region **204c**. In some embodiments, the substrate **202** may be a semiconductor substrate such as a silicon substrate. The substrate **202** may also include other semiconductors such as germanium (Ge), silicon carbide (SiC), silicon germanium (SiGe), or diamond. Alternatively, the substrate **202** may include a compound semiconductor and/or an alloy semiconductor. The substrate **202** may include various layers, including conductive or insulating layers formed on a semiconductor substrate. The substrate **202** may include various doping configurations depending on design requirements, as is known in the art. For example, different doping profiles (e.g., n wells or p wells) may be formed on the substrate **202** in regions designed for different device types (e.g., n-type field-effect transistors (NFET), or p-type field-effect transistors (PFET)). The suitable doping may include ion implantation of dopants and/or diffusion processes.

(21) The first, second and third regions **204a**, **204b** and **204c** are defined for accommodating different devices. For example, the first region **204a** may accommodate a high-voltage (HV) device while the second region **204b** may accommodate a low-voltage (LV) device. In some embodiments, the HV device used herein is a device having an operating voltage greater than that of the LV device. For example, but not limited thereto, the HV device may have an operating voltage between approximately 25V and approximately 35V, while the LV device may have an operating voltage between approximately 5V and approximately 15V. However, operating voltages can vary for different applications, thus they are not limited herein. For example, the LV device may have an operating voltage lower than approximately 2V. In some embodiments, the third region **204c** may accommodate a middle voltage (MV) device. The MV device referred to herein is a device having an operating voltage between those of the LV device and the HV device.

(22) In some embodiments, the HV and MV devices may be planar field-effect transistor (FET) devices, while the LV device may be a non-planar FET device, such as a fin-like FET (FinFET) device.

(23) In some embodiments, in operation **102**, a first isolation structure is formed in the first region **204a**. In some embodiments, the forming of the first isolation structure includes further operations. Still referring to FIG. 2, a patterned mask layer **206** is formed over the substrate **202**. In some embodiments, the patterned mask layer **206** may be a multiple-layered structure. For example, the patterned mask layer **206** may include a first layer **206-1** and a second layer **206-2**. The first layer **206-1** may be a silicon oxide layer, and the second layer **206-2** may be a silicon nitride layer, but the disclosure is not limited thereto.

(24) A suitable etching operation is performed to remove portions of the substrate **202** exposed through the patterned mask layer **206**. Accordingly, a mesa **208** is formed in the second region **204b**. In some embodiments, a top surface of the mesa **208** in the second region **204b** is higher than

a top surface of the substrate **202** in the first region **204a** and the third region **204c**, as shown in FIG. 2.

(25) Referring to FIG. 3, in some embodiments, another mask layer **210** is formed over the substrate **202**. In some embodiments, the mask layer **210** may be a multiple-layered structure. For example, the mask layer **210** may include a first layer **210-1** and a second layer **210-2**. The first layer **210-1** may be a silicon oxide layer, and the second layer **210-2** may be a silicon nitride layer, but the disclosure is not limited thereto. As shown in FIG. 3, the mask layer **210** may be conformally formed over the substrate **202**. Therefore, the mask layer **210** covers a top surface of the patterned mask layer **206**, a sidewall of the mesa **208** and the top surface of the substrate **202** in the first region **204a** and the third region **204c**.

(26) Referring to FIG. 4, the mask layer **210** is next patterned to exposed portions of the substrate **202** in the first region **204a** and the third region **204c**. A suitable etching operation is subsequently performed to remove the exposed portions of the substrate **202**. Accordingly, recesses **211a** and **211b** are formed. In such embodiments, the mesa **208** is protected by the patterned mask layers **206** and **210**. In some embodiments, a depth of the recess **211a** in the first region **204a** and a depth of the recess **211b** in the third region **204c** may be similar, but the disclosure is not limited thereto. In some embodiments, a width of the recess **211a** is different from a width of the recess **211b**. For example, the width of the recess **211a** in the first region **204a** is greater than the width of the recess **211b** in the third region **204c**. However, in some alternative embodiments, the widths of the recesses **211a** and **211b** may be similar, depending on different product designs.

(27) Referring to FIG. 5, in some embodiments, an insulating layer **212** is formed. The recesses **211a** and **211b** are filled with the insulating layer **212**. In some embodiments, the insulating layer **212** may include silicon oxide, but the disclosure is not limited thereto. In some embodiments, the insulating layer **212** not only fills the recesses **211a** and **211b**, but also covers a top surface of the patterned mask layer **210** over the mesa **208**. In such embodiments, a planarization (i.e., a chemical-mechanical polishing (CMP) operation) is performed to remove superfluous material such that a top surface of the insulating layer **212** and the top surface of the patterned mask layer **210** over the mesa **208** are aligned with each other, as shown in FIG. 5.

(28) Referring to FIG. 6, in some embodiments, a portion of the insulating layer **212** is removed to expose a portion of the substrate **202** in the first region **204a**. The exposed portion of the substrate **202** is then removed, thus forming a recess **213** in the insulating layer **212** and the substrate **202** in the first region **204a**, as shown in FIG. 6. In some embodiments the recess **213** may have a bottom formed of the substrate **202** and the first insulating layer **212**. For example, a portion of the bottom of the recess **213** is formed by the substrate **202** while another portion of the bottom of the recess **213** is formed by the first insulating layer **212**. Additionally, portions of the substrate **202** are exposed through a portion of a sidewall of the recess **213**, while portions of the insulating layer **212** are exposed through another portion of the sidewall of the recess **213**. In some embodiments, a well **214** may be formed prior to or after the forming of the recess **213**, depending on the process design.

(29) Referring to FIG. 7, in some embodiments, operation **103** may be performed to form a gate dielectric layer. In some embodiments, the forming of the gate dielectric layer may include further operations. For example, a dielectric layer **216** is formed in the recess **213**. In some embodiments, the dielectric layer **216** may be a thermal oxide layer. In such embodiments, the dielectric layer **216** may have a first portion **218a** formed over the substrate **202** and a second portion **218b** formed over the insulating layer **212**, wherein a thickness of the first portion **218a** is greater than a thickness of the second portion **218b**, as shown in FIG. 7.

(30) Referring to FIG. 8, in some embodiments, a portion of the insulating layer **212** and a portion of the patterned mask layer **210** are removed to form a recess **219** in the third region **204c**. Further, a portion of the substrate **202** in the third region **204c** is exposed through the recess **219**. In some embodiments, a well region **220** may be formed in the substrate **202** in the third region **204c**, as shown in FIG. 8. In such embodiments, a concentration of dopants in the well region **220** is

different from a concentration of dopants in the well region **214**, in order to accommodate devices of different operating voltages.

(31) Still referring to FIG. **8**, in some embodiments, after the forming of the well region **220**, a dielectric layer **222** is formed on a bottom of the recess **219**. In some embodiments, the dielectric layer **222** and the dielectric layer **216** may include similar materials, but the disclosure is not limited thereto. In some embodiments, a thickness of the dielectric layer **222** is less than a thickness of the dielectric layer **216**. In some embodiments, the thickness of the dielectric layer **222** may be between the thickness of the first portion **218a** and the thickness of the second portion **218b**. In some alternative embodiments, the thickness of the dielectric layer **222** may be less than the thicknesses of the first and second portions **218a** and **218b** of the dielectric layer **216**.

(32) Referring to FIG. **9**, in some embodiments, the recesses **213** and **219** are filled with a dielectric layer **224**. In some embodiments, a material of the dielectric layer **224** may be similar to that of the dielectric layer **216**, but the disclosure is not limited thereto. In some embodiments, a planarization such as a CMP operation may be performed to remove portions of the patterned mask layer **210**, the remaining patterned mask **206**, a portion of the insulating layer **212** and a portion of the dielectric layer **224**. Accordingly, a top surface of the remaining patterned mask layer **210**, a top surface of the remaining insulating layer **212** and a top surface of the dielectric layer **224** are aligned with each other. In some embodiments, the abovementioned top surfaces are aligned with the top surface of the mesa **208**.

(33) Referring to FIG. **10**, in some embodiments, an etching operation is performed to remove the patterned mask layer **210** and portions of the insulating layer **212** and the dielectric layer **224**. In such embodiments, an etchant with a high etching ratio of dielectric/insulating materials to the semiconductor material is used. As a result, a smaller portion of the mesa **208** may be consumed when removing the patterned mask layer **210**, the insulating layer **212** and the dielectric layer **224**. Further, the etching operation may be an isotropic etching operation. Accordingly, the mesa **208** is exposed. An isolation structure **230** is formed in the recess **211a** (shown in FIG. **4**), an isolation structure **232** is formed in the recess **211b** (shown in FIG. **4**), and a dielectric structure **234** including remaining portions of the dielectric layers **216** and **224** is formed. Further, a top surface of the substrate **202** in the first region **204a** and the third region **204c**, a top surface of the dielectric structure **234** (i.e., the remaining first portion **218a** of the dielectric layer **216** and the remaining dielectric layer **224**), a top surface of the remaining dielectric layer **222**, and top surfaces of the isolation structures **230** and **232** are substantially aligned with each other, as shown in FIG. **10**. In some embodiments, the dielectric structure **234** serves as a gate dielectric layer of an HV device to be subsequently formed, while the dielectric layer **222** serves as a gate dielectric layer of an MV device to be subsequently formed.

(34) Still referring to FIG. **10**, in some embodiments, doped regions **226** may be formed in the third region **204c** as needed. In some embodiments, the doped regions **226** may be lightly-doped drains (LDDs), but the disclosure is not limited thereto.

(35) Referring to FIG. **11**, in some embodiments, a sacrificial layer **236** is formed over the substrate **202**. Further, a top surface of the sacrificial layer **236** is formed to be aligned with the top surface of the mesa **208**. Thus, a substantially flush or flat surface is obtained. The flat surface is beneficial for subsequent operations.

(36) In operation **104**, a plurality of fin structures are formed. In some embodiments, the forming of the fin structures includes further operations. For example, as shown in FIG. **12**, a protection layer **238** may be formed over the first region **204a** and the third region **204c**. Subsequently, the plurality of fin structures **240** are formed in the second region **204b**. In some embodiments, a plurality of recesses **241** are concurrently formed. Further, the fin structures **240** are separated from each other by the recesses **241**. In some embodiments, the recess **241** may be used to define a region where the fin structures **240** are formed in the second region **204b**.

(37) Referring to FIG. **13**, in operation **105**, a plurality of isolation structures separating the fin

structures **240** are formed. In some embodiments, the forming of the isolation structures includes further operations. For example, an insulating layer **242** is formed to fill the recesses **241**. Further, the insulating layer **242** may cover top surfaces of the fin structures **240**, as shown in FIG. **13**. In some embodiments, a top surface of the insulating layer **242** is aligned with a top surface of the protection layer **238**, but the disclosure is not limited thereto.

(38) Referring to FIG. **14**, in some embodiments, the protection layer **238** is removed after the filling of the recesses **241** and the forming the insulating layer **242**.

(39) Referring to FIGS. **15A** and **15B**, an etching operation is performed to remove the sacrificial layer **236** and portions of the insulating layer **242**. Thus, the top surface of the substrate **202** in the first region **204a** and the third region **204c** is exposed. Further, the top surface of the dielectric structure **234**, the top surfaces of the isolation structures **230** and **232**, and the top surface of the dielectric layer **222** are exposed. In such embodiments, the remaining insulating layer **242** is referred to as the plurality of isolation structures **250**. As shown in FIGS. **15A** and **15B**, the isolation structures **250** not only separate the adjacent fin structures **240**, but also separate the fin structures **240** from other elements. Additionally, in some embodiments, the remaining mesa **208** is referred to as a dummy structure **242**.

(40) Still referring to FIGS. **15A** and **15B**, top surfaces of the isolation structures **250** are lower than the top surfaces of the fin structures **240**. In some embodiments, a thickness of the isolation structures **250** is substantially equal to a thickness of the dielectric structure **234**. Further, the top surfaces of the isolation structures **250** may be aligned with the top surface of the dielectric structure **234**, the top surface of the dielectric layer **222** and the top surfaces of the isolation structures **230** and **232**.

(41) A fin height H_f of each fin structure **240** is defined as a vertical distance between the top surface of the fin structure **240** and the top surface of the isolation structure **250**, as shown in FIG. **15B**. In some embodiments, a height of the dummy structure **242** is substantially equal to the fin height H_f of the fin structure **240**.

(42) In operation **106**, gate structures are formed. In some embodiments, the forming of the gate structures includes further operations. Referring to FIGS. **16A** and **16B**, gate structures **244a**, **244b** and **244c** are formed over the substrate **202**. The gate structure **244a** is formed in the first region **204a**. Further, the gate structure **244a** covers the dielectric structure **234** and a portion of the isolation structure **230**. The gate structure **244b** is formed in the second region **204b** and covers each of the fin structures **240**. The gate structure **244c** is formed in the third region **204c**. Further, the gate structure **244c** covers the dielectric layer **222** and a portion of the isolation structure **232**. As mentioned above, the dielectric structure **234** and the dielectric layer **222** respectively serve as the gate dielectric layers.

(43) In some embodiments, the gate structures **244a**, **244b** and **244c** are sacrificial gate structures. The sacrificial gate structures **244a**, **244b** and **244c** may respectively include a dielectric layer and a sacrificial semiconductor layer. In some embodiments, the semiconductor layers are made of polysilicon, but the disclosure is not limited thereto. In some embodiments, spacers **246** can be formed over sidewalls of the sacrificial gate structures **244a**, **244b** and **244c**. In some embodiments, the spacers **246** are made of silicon nitride (SiN), silicon carbide (SiC), silicon oxide (SiO), silicon oxynitride (SiON), silicon carbide or any other suitable material, but the disclosure is not limited thereto. In some embodiments, the spacers **246** are formed by deposition and etch-back operations.

(44) Referring to FIG. **17**, portions of the fin structure **240** covered by the gate structure **244b** serve as a channel region, and portions of the fin structure **240** exposed through the gate structure **244b** serve as a source/drain structure **248**. In some embodiments, a height of the source/drain structure **248** may be greater than heights of the fin structures **240**. In some embodiments, the source/drain structure **248** may be formed by forming recesses in the fin structures **240** and growing a strained material in the recesses by an epitaxial (epi) process. In addition, a lattice constant of the strained material may be different from a lattice constant of the fin structures **240**. Accordingly, the

source/drain structure **248** may serve as a stressor that improves carrier mobility. In some embodiments, a source/drain structure may be formed in the substrate **202** at two sides of the gate structure **244a** in the first region **204a**, and a source/drain structure may be formed in the substrate **202** at two sides of the gate structure **244c** in the third region **204c**, though not shown. The forming of the source/drain structures in the first and third regions **204a** and **204c** may be performed simultaneously with, prior to, or after the forming of the source/drain structure **248**.

(45) Referring to FIGS. **18A** and **18B**, in some embodiments, after the forming of the source/drain structures **248**, a dielectric structure **252** is formed to cover all the gate structures **244a**, **244b** and **244c** and the dummy structure **242** over the substrate **202**. In some embodiments, the dielectric structure **252** may include a contact etch stop layer (CESL). In some embodiments, the CESL can include silicon nitride, silicon oxynitride, and/or other applicable materials. The dielectric structure **252** may include an inter-layer dielectric (ILD) structure formed on the CESL in accordance with some embodiments. The ILD structure may include multilayers made of multiple dielectric materials, such as silicon oxide, silicon nitride, silicon oxynitride, tetraethoxysilane (TEOS), phosphosilicate glass (PSG), borophosphosilicate glass (BPSG), low-k dielectric material, and/or other applicable dielectric materials. Examples of low-k dielectric materials include, but are not limited to, fluorinated silica glass (FSG), carbon-doped silicon oxide, amorphous fluorinated carbon, parylene, bis-benzocyclobutenes (BCB), or polyimide. Next, a polishing process (e.g. a CMP operation) is performed on the dielectric structure **252** to expose top surfaces of the gate structures **244a**, **244b** and **244c**, as shown in FIGS. **18A** and **18B**.

(46) Referring to FIGS. **19A** and **19B**, in some embodiments, the sacrificial semiconductor layers of the gate structures **244a**, **244b** and **244c** are removed to form gate trenches **253a**, **253b** and **253c**. In some embodiments, the dielectric layer of the gate structure **244b** may be removed for forming an interfacial layer (IL). In some embodiments, the dielectric layers of the gate structures **244a** and **244c** may be left in the gate trench, though not shown. It should be noted that the removal of the dielectric layers may be performed depending on different process or product requirements. Accordingly, the fin structure **240** is exposed through the gate trench **253b**.

(47) Additionally, in some embodiments, the removal of the sacrificial semiconductor layer of the gate structure **244b** may be performed on the gate structure **244b** in the second region **204b**, while the gate structures **244a** and **244c** remain in the first and third regions **204a** and **204c**.

(48) Referring to FIGS. **20A** and **20B**, in some embodiments, metal gate electrodes **260a**, **260b** and **260c** are formed. In some embodiments, the forming of the metal gate electrodes **260a**, **260b** and **260c** may include further operations. In some embodiments, a high-k gate dielectric layer **262** is formed in the gate trench **253b**. In some embodiments, an IL layer may be formed prior to the forming of the high-k gate dielectric layer **262**, though not shown.

(49) The IL layer may include an oxide-containing material such as SiO or SiON. In some embodiments, the IL layer covers portions of the fin structures **240** exposed in the gate trench **253b**. In some embodiments, the high-k gate dielectric layers **262** may be conformally formed in the gate trench **253b**. Accordingly, the high-k gate dielectric layer **262** covers at least sidewalls of the gate trench **253b**. In some embodiments, the high-k gate dielectric layers **262** includes a high-k dielectric material having a high dielectric constant, for example, greater than that of thermal silicon oxide (~3.9). The high-k dielectric material may include hafnium oxide (HfO₂), zirconium oxide (ZrO₂), lanthanum oxide (La₂O₃), aluminum oxide (Al₂O₃), titanium oxide (TiO₂), yttrium oxide (Y₂O₃), strontium titanate (SrTiO₃), hafnium oxynitride (HfO_xNy), other suitable metal-oxides, or combinations thereof.

(50) In some embodiments, the high-k gate dielectric layer **262** may be formed in the gate trench **253b** in the second region **204b**, but the gate trenches **253a** and **253c** in the first and third regions **204a** and **204c** are free of the high-k gate dielectric layer **262**. In some embodiments, the high-k gate dielectric layer **262** may be formed in all the gate trenches **253a**, **253b** and **253c**, though not shown.

(51) In some embodiments, the metal gate electrodes **260a**, **260b** and **260c** respectively include a multiple metal layer **264**. In some embodiments, the multiple metal layer **264** includes at least a work function metal layer and a gap-filling metal layer. The work function metal layer may include n-type or p-type work function metal materials, depending on the product design. Further, the work function metal layer may be a single-layered structure or multilayers of two or more materials, but the disclosure is not limited thereto. In some embodiments, a gap-filling metal layer is formed to fill the gate trench **253a**, **253b** and **253c**. In some embodiments, the gap-filling metal layer can include conductive material such as Al, Cu, AlCu or W, but is not limited to the above-mentioned materials.

(52) Accordingly, a semiconductor structure **200** is obtained as shown in in FIGS. **20A** and **20B**. The semiconductor structure **200** includes the substrate **202** having the first region **204a**, the second region **204b** and the third region **204c**. As mentioned above, the first region **204a** may accommodate a first planar FET device such as an HV FET device **270a**, the second region **204b** may accommodate an non-planar FET device such as an LV FinFET device **270b**, and the third region **204c** may accommodate a second planar FET device such as an MV FET device **270c**. The arrangements of the first, second and third regions **204a**, **204b** and **204c** may be modified depending on different product design.

(53) The first planar FET device **270a** includes the isolation structure **230** in the substrate **202**, the gate electrode **260a** disposed over a portion of the isolation structure **230**, and the gate dielectric layer **234** between the substrate **202** and the gate electrode **260a**. As mentioned above, the gate electrode **260a** may be a metal gate electrode formed using an RPG operation. However, in other embodiments, the RPG operation may be ignored, and the gate electrode **260a** may be a polysilicon gate electrode. The gate dielectric layer **234** may include portions **216** and **224**, as shown in FIG. **14**. Further, the gate dielectric layer **234** has a thickness **T1** that is compatible with the HV requirements.

(54) The FinFET device **270b** includes the plurality of fin structures **240**, the metal electrode **260b** over the fin structures **240** and the high-k gate dielectric layer **262** between the metal gate electrode **260b** and the fin structures **240**. The high-k gate dielectric layer **262** has a thickness **T2**.

(55) The second planar FET device **270c** includes the isolation structure **232** in the substrate **202**, a gate electrode **260c** disposed over a portion of the isolation structure **232**, and the gate dielectric layer **222** between the substrate **202** and the gate electrode **260c**. As mentioned above, the gate electrode **260c** may be a metal gate electrode formed using an RPG operation. However, in other embodiments, the RPG operation may be ignored, and the gate electrode **260c** may be a polysilicon gate electrode. Further, the gate dielectric layer **222** has a thickness **T3** that is compatible with the MV requirements.

(56) As mentioned above, the three FET devices **270a**, **270b** and **270c** have different operating voltages: therefore, the thicknesses **T1**, **T2** and **T3** are different from each other. In some embodiments, the thickness **T1** of the gate dielectric layer **234** of the HV device **270a** is greater than the thickness **T3** of the gate dielectric layer **222** of the MV device **270c**, and the thickness **T3** of the gate dielectric layer **222** of the MV device **270c** is greater than the thickness **T2** of the high-k gate dielectric layer **262** of the LV FinFET device **270b**.

(57) The semiconductor structure **200** further includes the plurality of isolation structures **250** disposed in the second region **204b**. As mentioned above, the isolation structures **250** separate the adjacent fin structures **240** from each other. Further, the isolation structures **250** separate the LV FinFET device **270b** from other devices (i.e., the first and second planar devices **270a** and **270c**). In some embodiments, the isolation structures **230** and **232** are provided for devices having operating voltages greater than that of the LV FinFET device **270b**; therefore, depths **D1** and **D3** of the isolation structures **230** and **232** are greater than a depth **D2** of the isolation structure **250**. In some embodiments, the depth **D1** of the isolation structure **230** and the depth **D3** of the isolation structure **232** may be similar. However, in some alternative embodiments, the depth **D1** of the isolation

structure **230** is greater than the depth **D3** of the isolation structure **232**. Further, in some embodiments, because the isolation structure **230** is provided for the HV device **270a**, while the isolation structure **232** is provided for the MV device **270c**, a width of the isolation structure **230** is greater than a width of the isolation structure **232**, as shown in FIGS. **20A** and **20B**.

(58) Additionally, in some embodiments, the thickness **T1** of the gate dielectric layer **234** is substantially equal to the depth **D2** of the isolation structure **250**, but the disclosure is not limited thereto.

(59) In some embodiments, a top surface of the isolation structures **250**, a top surface of the isolation structure **230**, and a top surface of the isolation structure **232** are aligned with each other. Further, in some embodiments, a top surface of the gate dielectric layer **234** and a top surface of the gate dielectric layer **222** are aligned with the above-mentioned top surfaces.

(60) In some embodiments, heights of the gate electrodes **260a**, **260b** and **260c** are substantially the same. In such embodiments, top surfaces of the gate electrodes **260a**, **260b** and **260c** are aligned with each other.

(61) In some embodiments, the semiconductor structure **200** further includes a dummy structure **242** formed between the gate electrode **260b** and other elements (i.e., the gate electrode **260a**). A height of the dummy structure **242** may be substantially equal to the fin height **Hf** of the fin structures **240**. The dummy structure **242** includes a material same as a material of the substrate **202**. In some embodiments, the dummy structure **242** may be removed.

(62) In summary, the present disclosure provides a method for forming a semiconductor structure. The method may be integrated into an HKMG process. The method integrates a planar device and a non-planar device. In some embodiments, the method for forming the semiconductor structure includes forming isolation structures and gate dielectric layers for the planar device prior to forming the non-planar device. Thus, issues such as the isolation structures having different dimensions and the gate dielectric layers having different thicknesses are mitigated. The method thereby helps the semiconductor structure to meet multiple-V_t structure requirements.

(63) Some embodiments of the present disclosure provide a semiconductor structure. The semiconductor structure includes a substrate, a first FET device and a second FET device. The substrate has a first region and a second region. The first FET device is disposed in the first region, and the second FET device is disposed in the second region. The first FET device includes a first isolation structure disposed in the substrate, a first gate electrode disposed over a portion of the first isolation structure, and a first gate dielectric layer between the substrate and the first gate electrode. The first gate dielectric layer has a first thickness. The second FET device includes a plurality of fin structures, a plurality of second isolation structures separating the fin structures, a second gate electrode disposed over the plurality of fin structures, and a second gate dielectric layer between the second gate electrode and the plurality of fin structures. The second gate dielectric layer has a second thickness. The second thickness is less than the first thickness.

(64) Some embodiments of the present disclosure provide a semiconductor structure. The semiconductor structure includes a non-planar FET device, a first planar FET device and a second planar FET device. The non-planar FET device includes a plurality of fin structures, a metal gate electrode over the plurality of fin structures, and a first gate dielectric layer between the metal gate electrode and the plurality of fin structures. The first planar FET device includes a first isolation structure, a first gate electrode covering a portion of the first isolation structure, and a second gate dielectric layer under the first gate electrode. The second planar FET device includes a second isolation structure, a second gate electrode covering a portion of the second isolation structure, and a third gate dielectric layer under the second gate electrode. The first isolation structure has a first width, and the second isolation structure has a second width. The second width is less than the first width. A thickness of the first dielectric layer is less than a thickness of the third gate dielectric layer, and the thickness of the third gate dielectric layer is less than a thickness of the second gate dielectric layer.

(65) Some embodiments of the present disclosure provide a method for forming a semiconductor structure. The method includes following operations. A substrate having a first region and a second region is received. A first isolation structure is formed in the first region. A first gate dielectric layer is formed in the first region. A plurality of fin structures are formed in the second region after the forming of the first gate dielectric layer. A plurality of second isolation structures separating the fin structures are formed in the second region. A first gate electrode is formed over the first gate dielectric layer in the first region, and a second gate electrode is formed over the fin structures in the second region.

(66) The foregoing outlines features of several embodiments so that those skilled in the art may better understand the aspects of the present disclosure. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions, and alterations herein without departing from the spirit and scope of the present disclosure.

Claims

1. A method for forming a semiconductor structure, comprising: receiving a substrate having a first region and a second region; forming a first isolation structure in the first region; forming a first gate dielectric layer in the first region; forming a plurality of fin structures in the second region after the forming of the first gate dielectric layer; forming a plurality of second isolation structures separating the fin structures in the second region; and forming a first gate structure over the first gate dielectric layer in the first region and a second gate structure over the fin structures in the second region, wherein the forming of the first isolation structure and the first gate dielectric layer further comprises: forming a patterned mask layer over the substrate; forming a first recess in the first region; filling the first recess with a first insulating layer; forming a second recess exposing a portion of the first insulating layer and a portion of the substrate; and forming the first gate dielectric layer in the second recess.
2. The method of claim 1, wherein the forming of the plurality of fin structures and the forming of the second isolation structure further comprise: forming a mesa in the second region; removing portions of the mesa to form the plurality of fin structures and a plurality of third recesses separating the fin structures; filling the third recess with a second insulating layer; and removing a portion of the second insulating layer to form the second isolation structures.
3. The method of claim 1, further comprising forming a dummy structure during the forming of the fin structures.
4. The method of claim 1, further comprising replacing a first sacrificial gate of the first gate structure with a first metal gate, and replacing a second sacrificial gate of the second gate structure with a second metal gate.
5. A method for forming a semiconductor structure, comprising: receiving a substrate having a first region and a second region; forming a first isolation structure in the first region and a second isolation structure in the second region; forming a first gate dielectric layer in the first region and a second dielectric layer in the second region, wherein a thickness of the first gate dielectric layer is greater than a thickness of the second gate dielectric layer, a top surface of the first gate dielectric layer is aligned with a top surface of the second gate dielectric layer, and a bottom surface of the second gate dielectric layer is lower than a top surface of the second isolation structure; forming a doped region in the second region; and forming a first gate structure over the first gate dielectric layer in the first region and a second gate structure over the second gate dielectric layer in the second region.

6. The method of claim 5, wherein a top surface of the first isolation structure is aligned with the top surface of the second isolation structure.
7. The method of claim 6, wherein the top surface of the first isolation structure, the top surface of second isolation structure, the top surface of the first gate dielectric layer and the top surface of the second gate dielectric layer are aligned with each other.
8. The method of claim 5, wherein a width of the first isolation structure is greater than a width of the second isolation structure.
9. The method of claim 5, wherein the first gate structure comprises a first metal gate structure, and the second gate structure comprises a second metal gate structure.
10. The method of claim 9, further comprising: forming a first sacrificial gate structure over the first gate dielectric layer in the first region, and a second sacrificial gate structure over the second gate dielectric layer in the second region; removing the first sacrificial gate structure and the second sacrificial gate structure to form a first gate trench in the first region and a second gate trench in the second region; and forming the first metal gate structure in the first gate trench and the second metal gate structure in the second gate trench.
11. The method of claim 5, wherein a width of the first gate structure is greater than a width of the second gate structure.
12. A method for forming a semiconductor structure, comprising: receiving a substrate having a first region, a second region and a third region; forming a first isolation structure in the first region and a second isolation structure in the third region; forming a first gate dielectric layer in the first region and a second gate dielectric layer in the third region, wherein a thickness of the first gate dielectric layer is greater than a thickness of the second gate dielectric layer; forming a plurality of fin structures in the second region after the forming of first gate dielectric layer and the second gate dielectric layer; forming a plurality of third isolation structures separating the fin structures in the second region, wherein thicknesses of the third isolation structures are less than a thickness of the first isolation structure and less than a thickness of the second isolation structure; and forming a first metal gate structure over the first gate dielectric layer in the first region, a second metal gate structure over the fin structures in the second region, and a third metal gate structure over the second gate dielectric layer in the third region.
13. The method of claim 12, further comprising forming a dummy structure between the first isolation structure and at least one of the third isolation structures.
14. The method of claim 13, wherein a top surface of the fin structure is aligned with a top surface of the dummy structure.
15. The method of claim 13, wherein the forming of the dummy structure further comprises: forming a mesa over the substrate in the second region; and removing portions of the mesa to form the fin structures and the dummy structure.
16. The method of claim 15, wherein the dummy structure and from the fin structures are simultaneously formed.
17. The method of claim 12, wherein the forming of the first metal gate structure, the second metal gate structure and the third metal gate further comprises: forming a first sacrificial gate structure over the first gate dielectric layer, a second sacrificial gate structure over the fin structure, and a third sacrificial gate structure over the second gate dielectric layer; removing the first sacrificial gate structure to form a first gate trench, removing the second sacrificial gate structure to form a second gate trench, and removing the third sacrificial gate structure to form a third gate trench; and forming the first metal gate structure in the first gate trench, forming the second metal gate structure in the second gate trench, and forming the third metal gate structure in the third gate trench.
18. The method of claim 17, further comprising forming a doped region in the third region prior to the forming of the third sacrificial gate structure.
19. The method of claim 17, further comprising forming a third gate dielectric layer over the fin

structure in the second gate trench prior to the forming of the second metal gate structure.

20. The method of claim 19, wherein the thickness of the second gate dielectric layer is greater than a thickness of the third gate dielectric layer.
