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SEMICONDUCTOR DEVICE AND MANUFACTURING METHOD THEREOF

Abstract

A method of semiconductor fabrication includes forming a dielectric layer over a substrate. A dummy gate structure is formed on the dielectric layer, which defines a dummy gate dielectric region. A portion of the dielectric layer not included in the dummy gate dielectric region is etched to form a dielectric etch back region. A spacer element is formed on a portion of the dielectric etch back region, which abuts the dummy gate structure, and defines a spacer dielectric region. A height of the dummy gate dielectric region is greater than the height of the spacer dielectric region. A recessed portion is formed in the substrate, over which a strained material is selectively grown to form a strained recessed region adjacent the spacer dielectric region. The dummy gate structure and the dummy gate dielectric region are removed. A gate electrode layer and a gate dielectric layer are formed.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION [0001] The present application is a continuation of U.S. application Ser. No. 18/216,560 filed Jun. 29, 2023, which is a continuation of U.S. application Ser. No. 17/360,740 filed Jun. 28, 2021, now U.S. Pat. No. 11,735,662, which is a continuation of U.S. application Ser. No. 16/102,317 filed Aug. 13, 2018, now U.S. Pat. No. 11,049,970, which is a divisional of U.S. application Ser. No. 14/809,158, filed Jul. 24, 2015, now U.S. Pat. No. 10,050,147, the entire contents of each are incorporated herein by reference.

TECHNICAL FIELD

[0002] The disclosure relates to a semiconductor integrated circuit, and more particularly to a semiconductor device having a fin structure and its manufacturing process.

BACKGROUND

[0003] As the semiconductor industry has progressed into nanometer technology process nodes in pursuit of higher device density, higher performance, and lower costs, challenges from both fabrication and design issues have resulted in the development of three-dimensional designs, such as a fin field effect transistor (FinFET). FinFET devices typically include semiconductor fins with high aspect ratios and in which channel and source/drain (S/D) regions of semiconductor transistor devices are formed. A gate is formed over and along the sides of the fin structure (e.g., wrapping) utilizing the advantage of the increased surface area of the channel and S/D regions to produce faster, more reliable and better-controlled semiconductor transistor devices. In some devices, strained materials in S/D portions of the FinFET utilizing, for example, silicon germanium (SiGe), silicon carbide (SiC), and/or silicon phosphide (SiP) may be used to enhance carrier mobility.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] The present disclosure is best understood from the following detailed description when read with the accompanying figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale and are used for illustration purposes only. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

[0005] FIGS. 1A-8B show exemplary sequential processes for manufacturing the FinFET device according to one embodiment of the present disclosure.

[0006] FIGS. 9-15B show exemplary sequential processes for manufacturing the FinFET device according to another embodiment of the present disclosure.

DETAILED DESCRIPTION

[0007] It is to be understood that the following disclosure provides many different embodiments, or examples, for implementing different features of the invention. Specific embodiments or examples of components 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, dimensions of elements are not limited to the disclosed range or values, but may depend upon process conditions and/or desired properties of the device. Moreover, 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 interposing the first and second features, such that the first and second features may not be in direct contact. Various features may be arbitrarily drawn in different scales for simplicity and clarity.

[0008] Further, spatially relative terms, such as “beneath,” “below,” “lower,” “above,” “upper” 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. In addition, the term “made of” may mean either “comprising” or “consisting of.”

[0009] As noted above, a gate is formed over and along the sides of the fin structure (e.g., wrapping) utilizing the advantage of the increased surface area of the channel and S/D regions to produce faster, more reliable and better-controlled semiconductor transistor devices. One process of implementing the gate is termed a “gate last” or “replacement gate” methodology. In such a process, a dummy (e.g., polysilicon) gate is initially formed, various processes associated with the semiconductor device are performed, and the dummy gate is subsequently removed and replaced with a gate (e.g., metal gate). During the process of removing the dummy gate, a region in spacer dielectric regions below spacer elements adjacent the dummy gate may be narrowed. Strained materials in S/D portions may be removed due to the narrower region of spacer dielectric regions, thus creating gate to S/D encroachment and poor isolation.

[0010] FIGS. **1A-8B** show exemplary processes for manufacturing a semiconductor FET device having a fin structure (FinFET). It is understood that additional operations can be provided before, during, and after operations shown by FIGS. **1A-8B**, and some of the operations described below can be replaced or eliminated, for additional embodiments of the method. The order of the operations may be interchangeable.

[0011] As shown in FIG. **1A**, fin structures are fabricated over a core region and over a peripheral region on a substrate. In some embodiments, the core region refers to a part of a core circuit in an electronic system that primarily performs logical operations, and the peripheral region refers to a part of a peripheral circuit (e.g., I/O circuit) in the electronic system that performs, for example, data input and data output operations. FIG. **1A** is an exemplary perspective view of the FinFET device at one of the various stages of the fabrication process according to one embodiment. FIG. **1B** is an exemplary cross sectional view along the line a-a of FIG. **1A**.

[0012] A fin structure **12** includes a first fin structure **121** corresponding to a core region and a second fin structure **122** corresponding to a peripheral region. Although the first fin structure **121** and the second fin structure **122** are disposed adjacent each other (as part of the same fin structure **12**) in FIG. **1A** for an illustrative purpose, they are not necessarily disposed adjacent each other, and the first fin structure **121** and the second fin structure **122** may be disposed in different regions and separately formed in a semiconductor device. The fin structure **12** is formed over a substrate **10** and protrudes from an isolation insulating layer **11**. To fabricate a fin structure, a mask layer is formed over the substrate **10** by, for example, a thermal oxidation process and/or a chemical vapor deposition (CVD) process. The substrate **10** is, for example, a p-type silicon substrate. In other

embodiments, the substrate **10** is an n-type silicon substrate. The mask layer includes, for example, a pad oxide (e.g., silicon oxide) layer and a silicon nitride mask layer in some embodiments. [0013] Alternatively, the substrate **10** may comprise another elementary semiconductor, such as germanium; a compound semiconductor including IV-IV compound semiconductors such as SiC and SiGe, III-V compound semiconductors such as GaAs, GaP, GaN, InP, InAs, InSb, GaAsP, AlGaIn, AlInAs, AlGaAs, GaInAs, GaInP, and/or GaInAsP; or combinations thereof. In one embodiment, the substrate **10** is a silicon layer of an SOI (silicon-on insulator) substrate. When an SOI substrate is used, the fin structure may protrude from the silicon layer of the SOI substrate or may protrude from the insulator layer of the SOI substrate. In the latter case, the silicon layer of the SOI substrate is used to form the fin structure. Amorphous substrates, such as amorphous Si or amorphous SiC, or insulating material, such as silicon oxide may also be used as the substrate **10**. The substrate **10** may include various regions that have been suitably doped with impurities (e.g., p-type or n-type conductivity).

[0014] In this embodiment, a bulk silicon wafer is used as a starting material and constitutes the substrate **10**. However, in some embodiments, other types of substrate may be used as the substrate **10**. For example, a silicon-on-insulator (SOI) wafer may be used as a starting material, and the insulator layer of the SOI wafer constitutes the substrate **10** and the silicon layer of the SOI wafer is used for the fin structure **12**.

[0015] The pad oxide layer may be formed by using thermal oxidation or a CVD process. The silicon nitride mask layer may be formed by a physical vapor deposition (PVD), such as a sputtering method, a CVD, plasma-enhanced chemical vapor deposition (PECVD), an atmospheric pressure chemical vapor deposition (APCVD), a low-pressure CVD (LPCVD), a high density plasma CVD (HDPCVD), an atomic layer deposition (ALD), and/or other processes.

[0016] The thickness of the pad oxide layer is in a range of about 2 nm to about 15 nm and the thickness of the silicon nitride mask layer is in a range of about 2 nm to about 50 nm in some embodiments. A mask pattern is further formed over the mask layer. The mask pattern is, for example, a resist pattern formed by lithography operations.

[0017] By using the mask pattern as an etching mask, a hard mask pattern of the pad oxide layer and the silicon nitride mask layer is formed. The width of the hard mask pattern is in a range of about 5 nm to about 40 nm in some embodiments. In certain embodiments, the width of the hard mask patterns is in a range of about 7 nm to about 12 nm.

[0018] By using the hard mask pattern as an etching mask, the substrate **10** is patterned into fin structure **12** by trench etching using a dry etching method and/or a wet etching method. A height (Ht) of the fin structure **12** is in a range of about 20 nm to about 300 nm. In certain embodiments, the height is in a range of about 30 nm to about 150 nm. When the heights of the fin structures are not uniform, the height from the substrate may be measured from the plane that corresponds to the average heights of the fin structures. The width of the fin structure **12** is in a range of about 5 nm to 15 nm.

[0019] As shown in FIG. 1A, one fin structure **12** extends in the Y direction. However, the number of the fin structures is not limited to one. The number may be two, three, four or five or more. In addition, one or more dummy fin structures may be disposed adjacent both sides of the fin structure **12** to improve pattern fidelity in patterning processes. The width of the fin structure **12** is in a range of about 4 nm to about 40 nm in some embodiments, and may be in a range of about 5 nm to about 15 nm in certain embodiments. The height (Ht) of the fin structure **12** is in a range of about 20 nm to about 300 nm in some embodiments, and may be in a range of about 30 nm to 150 nm in other embodiments. One skilled in the art will realize, however, that the dimensions and values recited throughout the descriptions are merely examples, and may be changed to suit different scales of integrated circuits.

[0020] After forming the fin structure, an isolation insulating layer **11** is formed over the fin structure **12**. The isolation insulating layer **11** includes one or more layers of insulating materials

such as silicon oxide, silicon oxynitride or silicon nitride, formed by LPCVD (low pressure chemical vapor deposition), plasma-CVD or flowable CVD. In the flowable CVD, flowable dielectric materials instead of silicon oxide are deposited. Flowable dielectric materials, as their name suggests, can “flow” during deposition to fill gaps or spaces with a high aspect ratio. Usually, various chemistries are added to silicon-containing precursors to allow the deposited film to flow. In some embodiments, nitrogen hydride bonds are added. Examples of flowable dielectric precursors, particularly flowable silicon oxide precursors, include a silicate, a siloxane, a methyl silsesquioxane (MSQ), a hydrogen silsesquioxane (HSQ), an MSQ/HSQ, a perhydrosilazane (TCPS), a perhydro-polysilazane (PSZ), a tetraethyl orthosilicate (TEOS), or a silyl-amine, such as trisilylamine (TSA). These flowable silicon oxide materials are formed in a multiple-operation process. After the flowable film is deposited, it is cured and then annealed to remove undesired element(s) to form silicon oxide. When the undesired element(s) are removed, the flowable film densifies and shrinks. In some embodiments, multiple anneal processes are conducted.

[0021] The flowable film is cured and annealed more than once. The flowable film may be doped with boron and/or phosphorous. The isolation insulating layer **11** may be formed by one or more layers of SOG, SiO, SION, SiOCN and/or fluoride-doped silicate glass (FSG) in some embodiments.

[0022] After forming the isolation insulating layer **11** over the fin structure **12** a planarization operation is performed so as to remove part of the isolation insulating layer **11** and the mask layer (the pad oxide layer and the silicon nitride mask layer). The planarization operation may include a chemical mechanical polishing (CMP) and/or an etch-back process. Then, the isolation insulating layer **11** is further removed so that an upper part of the fin structure **12** which is to become a channel layer **12A**, is exposed, as shown in FIG. **1A**.

[0023] In certain embodiments, the partially removing of the isolation insulating layer **11** may be performed using a wet etching process, for example, by dipping the substrate in hydrofluoric acid (HF). In other embodiments, the partially removing the isolation insulating layer **11** may be performed using a dry etching process. For example, a dry etching process using CHF₃ or BF₃ as etching gases may be used.

[0024] After forming the isolation insulating layer **11**, a thermal process, for example, an anneal process, may be performed to improve the quality of the isolation insulating layer **11**. In certain embodiments, the thermal process is performed by using rapid thermal annealing (RTA) at a temperature in a range of about 900° C. to about 1050° C. for about 1.5 seconds to about 10 seconds in an inert gas ambient, such as an N₂, Ar or He ambient.

[0025] First dummy gate structure **60** and second dummy gate structure **60B** are formed as shown in FIGS. **1A** and **1B**.

[0026] A dielectric layer **20** and a poly silicon layer are formed over the isolation insulating layer **11** and the exposed fin structure **12** and then patterning operations are performed so as to obtain a first dummy gate structure **60** and a second dummy gate structure **60B**. The first dummy gate structure **60** includes a first dummy gate electrode layer **50** made of poly silicon and a dummy gate dielectric region **20A**. The second dummy gate **60B** includes a second dummy gate electrode layer **50B** made of poly silicon and a dummy gate dielectric region **20B**.

[0027] The patterning of the poly silicon layer in the first dummy gate structure **60** is performed by using a hard mask **32** including two layers **30**, **40** in some embodiments. In some embodiments, the first layer **30** may be a silicon oxide layer and the second layer **40** may be a silicon nitride layer. In other embodiments, the first layer **30** may be a silicon nitride layer and the second layer **40** may be a silicon oxide layer. The patterning of the poly silicon layer in the second dummy gate structure **60B** is also performed by using a hard mask **32B** including a silicon nitride layer **40B** and a silicon oxide layer **30B** in some embodiments. In other embodiments, the order of the silicon nitride and silicon oxide layers may be reversed.

[0028] The dummy gate dielectric layer **20** may be silicon oxide formed by thermal oxidation,

CVD, PVD, ALD, e-beam evaporation, or other suitable process. In some embodiments, the dielectric layer **20** may include one or more layers of high-k dielectrics, such as hafnium oxide (HfO₂). High-k dielectrics comprise metal oxides. Examples of metal oxides used for high-k dielectrics include oxides of Li, Be, Mg, Ca, Sr, Sc, Y, Zr, Hf, Al, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, and/or mixtures thereof. In some embodiments, a thickness of the gate dielectric layer **20** is in a range of about 3 nm to about 4 nm. That is, the height (H) of the dummy gate dielectric region **20A** is in a range of about 3 nm to about 4 nm. The dummy gate dielectric region **20A** is defined by a first sidewall and a second sidewall of the first dummy gate structure **60**, and the first sidewall and second sidewall extend substantially perpendicular to a top surface of the dielectric layer **20**. That is, the width (W2) of the dummy gate dielectric region **20A** is the same as the width (W1) of the dummy gate electrode layer **50**.

[0029] In some embodiments, the first and second dummy gate electrode layers **50**, **50B** may comprise a single layer or multilayer structure. The first and second dummy gate electrode layers **50**, **50B** may include polysilicon and/or other suitable layers. The first and second dummy gate electrode layers **50**, **50B** may be formed by depositing a layer of polysilicon. The layer of polysilicon may then be patterned and etched into a polysilicon gate electrode. The first and second dummy gate electrode layers **50**, **50B** may be formed using a suitable process such as ALD, CVD, PVD, plating, patterning or combinations thereof. In the present embodiment, the width of the first and second dummy gate electrode layer **50**, **50B** is in the range of about 20 nm to about 300 nm. In some embodiments, a thickness of the first and second dummy gate electrode layer **50**, **50B** is in a range of about 25 nm to about 240 nm. The width (W3) of the second dummy gate electrode layer **50B** is greater than that of the first dummy gate electrode layer **50** in some embodiments.

[0030] As shown in FIG. 2, a portion of the dielectric layer **20** is partially etched using an etching process (wet etch, dry etch, plasma etch, etc.) that is selective to the hard mask **32** to form a dielectric etch back region **22**. The dielectric etch back region **22** is a region other than the dummy gate dielectric region **20A** and the gate dielectric region **20B** and is adjacent the dummy gate dielectric region **20A** and the gate dielectric region **20B**. The etching process may include removal of the dielectric layer **20** by one or more etching cycles. Each etching cycle may include removal of 0.5 nm to 1 nm of the dielectric layer. The total thickness of the dielectric layer **20** that is removed is in a range of about 1 nm to about 3 nm. That is, the difference between the height (H) of the dummy gate dielectric region **20A** or the gate dielectric region **20B** and the height (h) of the dielectric etch back region **22** is in a range of about 1 nm to about 3 nm. In some embodiments, a surface treatment process may be performed in the dielectric etch back region **22** such as oxidation, nitridation or ion implantation (e.g., carbon ions).

[0031] As shown in FIG. 3, spacer elements **70A**, **70B**, **71A** and **71B** are formed over the dummy gate structures **60** and **60B**, respectively, and on a portion of the dielectric etch back region **22**. The spacer elements **70A** and **70B** include two layers of spacer element layers in this embodiment. The thickness of a spacer element layer may be between approximately 2 nm and approximately 5 nm. In other embodiments, the spacer element layer may be greater than approximately 5 nm in thickness. The number of spacer element layers is not limited to two. The number may be one, three, four or five or more. The spacer elements **70A** and **70B** are disposed adjacent both major vertical sides of the dummy gate structure **60**, such as the first sidewall **60S1** and second sidewall **60S2** respectively. Spacer elements **70A** and **70B** are disposed facing source region **80A** and drain region **80B**, respectively. The spacer element layer may include one or more layers of silicon nitride, silicon oxide, silicon oxynitride, SiCN, SiOCN, and/or other suitable dielectric materials. The materials of the two layers of the spacer element layers may be different in some embodiments, and may be the same in other embodiments.

[0032] In some embodiments, the spacer elements **71A** and **71B** are formed in accordance with the details described with reference to the spacer elements **70A** and **70B**, respectively. In some embodiments, the spacer elements **71A** and **71B** are simultaneously formed by the same operations

as the spacer elements **70A** and **70B**. Spacer elements **71A** and **71B** are disposed adjacent both major vertical sides of the second dummy gate structure **60B**, such as a third sidewall **61S1** and a fourth sidewall **61S2** respectively. Spacer elements **71A** and **71B** are disposed facing source region **80C** and drain region **80D**, respectively.

[0033] A spacer dielectric region **22A** is defined by a first sidewall and a second sidewall of the spacer element **70A**, and the first sidewall and second sidewall extend substantially perpendicular to a top surface of the spacer dielectric region **22A**. A spacer dielectric region **22B**, is defined by a first sidewall and a second sidewall of the spacer element **70B**, and the first sidewall and second sidewall extend substantially perpendicular to a top surface of the spacer dielectric region **22B**. That is, the width of the spacer dielectric region **22A** or **22B** is equal to or less than the width of the spacer element **70A** or **70B**, respectively.

[0034] Similarly, a spacer dielectric region **22C** is defined by a first sidewall and a second sidewall of the spacer element **71A**, and the first sidewall and second sidewall extend substantially perpendicular to a top surface of the spacer dielectric region **22C**. A spacer dielectric region **22D** is defined by a first sidewall and a second sidewall of the spacer element **71B**, and the first sidewall and second sidewall extend substantially perpendicular to a top surface of the spacer dielectric region **22D**. That is, the width of the spacer dielectric region **22C** or **22D** is equal to or less than the width of the spacer element **71A** or **71B**, respectively.

[0035] The first fin structure **121** and the second fin structure **122** in FIG. 3 are subsequently etched down to form one or more recessed portions (not shown). In some embodiments, using the pair of spacer elements **70A** and **70B** (and the first dummy gate structure **60**) as hard masks, a biased etching process is performed to recess a top surface of the channel layer **12A** that is unprotected or exposed to form the recessed portions of the first fin structure **121**. Similarly, using the pair of spacer elements **71A** and **71B** (and the second dummy gate structure **60B**) as hard masks, a biased etching process is performed to recess a top surface of the channel layer **12A** that is unprotected or exposed to form the recessed portions of the second fin structure **122**.

[0036] As shown in FIG. 3, a strained material may be selectively grown over the recessed portions and extend over the top surface of the channel layer **12A**. In at least one embodiment, the strained material, such as silicon carbide (SiC) and SiP, is epi-grown by a LPCVD process to form the source region **80A** or **80C** and drain region **80B** or **80D** when the FinFET is an n-type FinFET. In at least another embodiment, the strained material, such as silicon germanium (SiGe), is epi-grown by a LPCVD process to form the source region **80A** or **80C** and drain region **80B** or **80D** when the FinFET is a p-type FinFET. The general operations for manufacturing a recessed S/D structure with strain materials (or stressor) in the fin structure are disclosed in U.S. Pat. No. 8,440,517, the entire contents of which are incorporated herein by reference.

[0037] As shown in FIG. 4, additional spacer element layers **70C** and **70D** may be formed adjacent the spacer elements **70A** and **70B**, such as adjacent sidewalls **60S3** and **60S4**, respectively. The additional spacer element layers **70C** and **70D** are formed after the source regions **80A** and **80B** are formed. The additional spacer element layers **70C** and **70D** may be formed using the same material and the same operations for forming the spacer element layers in spacer elements **70A** and **70B**, as discussed with reference to FIG. 3. The thickness of additional spacer element layer may be between approximately 2 nm and approximately 5 nm. In other embodiments, the thickness of the additional spacer element layers **70C** and **70D** may be greater than 5 nm. The number of additional spacer element layers is not limited to two. The number may be one, three, four or five or more. In addition, the additional spacer element layers **70C** and **70D** are disposed adjacent both main sides of the dummy gate electrode **50**. The additional spacer element layer may include one or more layers of silicon nitride, silicon oxide, silicon oxynitride, SiCN, SiOCN, and/or other suitable dielectric materials. In some embodiments, the additional spacer element layer **70C** may be formed before the source region **80A** is formed. The additional spacer element layer **70D** is formed after the drain region **80B** is formed.

[0038] In some embodiments, additional spacer element layers **71C** and **71D** are formed in accordance with the details described with reference to the additional spacer element layers **70C** and **70D**, respectively. In some embodiments, the additional spacer element layers **71C** and **71D** are formed by the same operations as the additional spacer element layers **70C** and **70D**.

[0039] In some embodiments, an inter-layer dielectric (ILD) layer **90** may be formed over a portion of the channel layer **12A**, the source regions **80A**, **80C** and the drain regions **80B**, **80D**. The ILD layer **90** may be formed by chemical vapor deposition (CVD), high density plasma CVD (HDP-CVD), spin-on deposition, physical vapor deposition (PVD or sputtering), or other suitable methods. The ILD layer **90** may include silicon oxide, silicon oxynitride, a low-k material, and/or other suitable dielectric. The ILD layer **90** may be formed on and surrounding the first dummy gate structure **60** and the second dummy gate structure **60B**. The ILD layer **90** may be conformably deposited and a chemical mechanical polish (CMP) process performed to planarize the material. The first dummy gate structure **60** and the second dummy gate structure **60B** may serve as a planarization stopper for the CMP process. In other words, the CMP process may be stopped at the exposure of the top surface of the first dummy gate structure **60** and the second dummy gate structure **60B**. In some embodiments, the hard mask **32** and part of the spacer elements **70A**, **70B** and/or additional spacer element layers **70C**, **70D** are removed from the first dummy gate structure **60** by the CMP process. In some embodiments, the hard mask **32B** and part of the spacer elements **71A**, **71B** and/or additional spacer element layers **71C**, **71D** are removed from the second dummy gate structure **60B** by the CMP process.

[0040] As shown in FIGS. **5-6**, the first dummy gate structure **60** is removed. The first dummy gate structure **60** removal may include removing the dummy gate electrode **50** as shown in FIG. **5** and the dummy gate dielectric region **20A** as shown in FIG. **6**. The removal of the first dummy gate structure **60** provides an opening between the spacer element **70A** and the spacer element **70B** within which a metal gate will be formed, as is typically performed in a replacement gate process. The dummy gate electrode **50** may be removed by an etching solution such as, for example, aqueous ammonia, and/or other suitable etchant. In an alternative embodiment, the dummy gate electrode **50** may be removed by a suitable dry etching process. Exemplary etchants include chlorine based etchants.

[0041] In some embodiments, the dummy gate dielectric region **20A** may be removed using an etching process (wet etch, dry etch, plasma etch, etc.). The removal of the dummy gate dielectric region **20A** may expose a top surface of the channel layer **12A**. It is noted that the spacer dielectric region **22A** and **22B** remain on the channel layer **12A** underlying the spacer element **70A** and the spacer element **70B** respectively.

[0042] As shown in FIGS. **5-6**, a part of the second dummy gate structure **60B** is removed. The second dummy gate structure **60B** removal may include removing the dummy gate electrode **50B** as shown in FIG. **5**. The dummy gate electrode **50B** may be removed by an etching solution such as, for example, aqueous ammonia, and/or other suitable etchant. In an alternative embodiment, the dummy gate electrode **50B** may be removed by a suitable dry etching process. Example etchants include chlorine based etchants. In some embodiments, the gate dielectric region **20B** remains on the channel layer **12A** and the spacer dielectric region **22C** and **22D** remain on the channel layer **12A** underlying the spacer element **71A** and the spacer element **71B** respectively.

[0043] As shown in FIG. **7**, gate structures are formed in the opening provided by the removal of the first dummy gate structure **60** and the part of the second dummy gate structure **60B** to form FinFET devices **100** and **200**. FIG. **8A** is an exemplary planar view of a FinFET device **100** disposed in a core region as shown in FIG. **7**. FIG. **8B** is an exemplary planar view of a FinFET device **200** disposed in a peripheral region as shown in FIG. **7**. In one embodiment, the gate structure of the FinFET device **100** includes an interfacial layer **110**, a high-k dielectric layer **120**, a metal layer **140** and/or other suitable materials for a gate structure. In one embodiment, the gate structure of the FinFET device **200** includes the dielectric region **20B**, a high-k dielectric layer

120B, a metal layer **140B** and/or other suitable materials for a gate structure. In other embodiments, the gate structure of the FinFET device **100** or **200** may further include capping layers, etch stop layers, and/or other suitable materials. The interfacial layer **110** may include a dielectric material such as silicon oxide layer (SiO₂). The interfacial layer **110** may be formed by chemical oxidation, thermal oxidation, atomic layer deposition (ALD), CVD, and/or other suitable processes. [0044] In some embodiments, the high-k dielectric layers **120** and **120B** may comprise one or more layers of metal oxides. Examples of metal oxides used for high-k dielectrics include oxides of Li, Be, Mg, Ca, Sr, Sc, Y, Zr, Hf, Al, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, and/or mixtures thereof. In this embodiment, hafnium oxide (HfO₂) is used. The high-k dielectric layers **120** and **120B** may be formed by atomic layer deposition (ALD), chemical vapor deposition (CVD), physical vapor deposition (PVD), and/or other suitable methods.

[0045] The metal layers **140** and **140B** may include one or more layers of Al, Cu, W, Ti, Ta, TiN, TiAl, TiAlC, TiAlN, TaN, NiSi, CoSi, other conductive materials with a work function compatible with the substrate material, or combinations thereof. The metal layers **140** and **140B** may be formed by CVD, PVD, plating, and/or other suitable processes. One or more CMP processes may be performed during the formation of the gate structure.

[0046] In some embodiments, the gate voltage of the FinFET **200** may be higher than that of the FinFET **100**, which requires the gate dielectric layer **20B** of the FinFET **200** to be thicker than the interfacial layer **110** of the FinFET **100**.

[0047] It is understood that the structures shown in FIGS. **1A-8B** may undergo further CMOS processes to form various features such as contacts/vias, interconnect metal layers, dielectric layers, passivation layers, etc.

[0048] FIGS. **9-15B** show another embodiment of the present disclosure. In the previous embodiment, a portion of the dielectric layer **20** is etched using an etching process to form the dielectric etch back region **22** including spacer dielectric regions **22A**, **22B**, **22C** and **22D** as shown in FIGS. **2-3**.

[0049] Instead of etching a portion of the dielectric layer **20**, no etching is performed on the dielectric layer **20** as shown in FIG. **9**. That is, there is no difference between the height of the dummy gate dielectric region **20A** and the height of the spacer dielectric region **20C** or **20D**. There is no difference between the height of the gate dielectric region **20B** and the height of the spacer dielectric region **20E** or **20F**.

[0050] In one embodiment, the height (h) of the spacer dielectric regions **20C**, **20D**, **20E**, **20F** and the gate dielectric regions **20A**, **20B** is in a range of about 1 nm to 3 nm.

[0051] In some embodiments, source regions **81A**, **81C**, drain regions **81B**, **81D**, spacer elements **72A**, **72B**, and spacer elements **73A**, **73B** as shown in FIG. **9** may be formed in accordance with the details described with reference to FIG. **3**. Subsequently, as shown in FIG. **10**, the dummy gate electrode layer **50**, **50B**, ILD layer **90**, and additional spacer element layers **72C**, **72D**, **73C** and **73D** may be formed and processed in accordance with the details described with reference to FIG. **4**. As shown in FIG. **11**, the dummy gate electrode layer **50** and **50B** in FIG. **10** may be removed in accordance with the details described with reference to FIG. **5**. As shown in FIG. **12**, a multi-layer (e.g., bi-layer) structure of dielectric layers **21** is deposited on the dummy gate dielectric region **20A**. A multi-layer (e.g., bi-layer) structure of dielectric layers **21B** is deposited on the gate dielectric region **20B**. Dielectric layers **21**, **21B** may include silicon oxide formed by thermal oxidation, CVD, PVD, ALD, e-beam evaporation, or other suitable process. In one embodiment, the thickness of the dielectric layers **21**, **21B** is in a range of about 1 nm to about 3 nm. In some embodiments, the dielectric layers **21**, **21B** may include a single dielectric layer. In some embodiments, a surface treatment process may be performed on a portion of the dielectric layer **20** not covered by the dummy gate electrode layer **50**, **50B**, such as including the spacer dielectric regions **20C**, **20D**, **20E**, **20F**, before forming the source regions **81A**, **81C**, drain regions **81B**, **81D**, spacer elements **72A**, **72B**, and spacer elements **73A**, **73B**.

[0052] As shown in FIG. 13, the dummy gate dielectric region **20A** and the dielectric layers **21** are removed using an etching process (wet etch, dry etch, plasma etch, etc.). The removal of the dummy gate dielectric region **20A** may expose a top surface of the channel layer **12A**. It is noted that the spacer dielectric region **20C** and **20D** remain on the channel layer **12A** underlying the spacer element **72C** and the spacer element **72D** respectively. As shown in FIG. 13, the dielectric layer **21B** remains on the dielectric region **20B**. As shown in FIG. 14, a gate structure is formed in the opening provided by the removal of the first dummy gate structure **60** to form a FinFET **100A** in accordance with the details described with reference to FIG. 7. The gate structure may include an interfacial layer **111**, a high-k dielectric layer **121**, a metal layer **141** and/or other suitable materials for a gate structure. A gate structure including the metal layer **141B** and the high-k dielectric layer **121B** of a FinFET **200A** is formed in accordance with the details described with reference to FIG. 7.

[0053] It is understood that the device shown in FIGS. 9-14B may undergo further CM OS processes to form various features such as contacts/vias, interconnect metal layers, dielectric layers, passivation layers, etc.

[0054] In some embodiments, the gate voltage of the FinFET **200A** may be higher than the Fin FET **100A**, which requires the height of the gate dielectric layer **20B** and the dielectric layer **21B** of the FinFET **200A** to be thicker than interfacial layer **111** of the FinFET **100A**. FIG. 15A is an exemplary planar view of the FinFET device **100A** disposed in a core region as shown in FIG. 14. FIG. 15B is an exemplary planar view of the FinFET device **200A** disposed in a peripheral region as shown in FIG. 14.

[0055] The various embodiments or examples described herein offer several advantages over the existing art. For example, by optimizing the height of the spacer dielectric region and/or the difference between the height of the dummy gate dielectric region and height of the spacer dielectric region, it is possible to improve the immunity against the etching solution (e.g., dilute-HF and/or aqueous ammonia) for the spacer dielectric region, for example due to surface tension and capillary effects. It is also possible to improve gate-to-S/D isolation and device life time under hot carrier degradation. In another example, by using the surface treatment process to the spacer dielectric region, it is possible to improve the immunity against the etching solution (e.g., dilute-HF and/or aqueous ammonia) for the spacer dielectric region.

[0056] It will be understood that not all advantages have been necessarily discussed herein, no particular advantage is required for all embodiments or examples, and other embodiments or examples may offer different advantages. In one example, although the processes described with reference to FIGS. 1A-15B are associated with a semiconductor FET device having a fin structure (FinFET), the processes described with reference to FIGS. 1A-15B may apply to a planar semiconductor device such as a planar MOSFET.

[0057] In accordance with one aspect of the present disclosure, a method of semiconductor fabrication includes forming a dielectric layer over a substrate. A first dummy gate structure is formed on the dielectric layer so that the dielectric layer includes a first gate dielectric region disposed below and defined by the first dummy gate structure. A portion of the dielectric layer not included in the first gate dielectric region is etched to form a dielectric etch back region adjacent the first gate dielectric region. A first spacer element is formed on a portion of the dielectric etch back region and on sidewalls of the first dummy gate structure, and the first spacer element abuts the dummy gate structure, the portion of the dielectric etch back region includes a first spacer dielectric region disposed below and defined by the first spacer element, and a height of the first gate dielectric region is greater than the height of the first spacer dielectric region. A first recessed portion is formed in the substrate. A strained material is selectively grown over the first recessed portion of the substrate to form a first strained recessed region, and the first strained recess region is adjacent the first spacer dielectric region. The first dummy gate structure and the first gate dielectric region are removed to form a first opening. A first gate structure including a gate

electrode layer and a gate dielectric layer is formed in the first opening.

[0058] In accordance with another aspect of the present disclosure, a method of semiconductor fabrication includes forming a first dielectric layer over a substrate. A first dummy gate structure is formed on the first dielectric layer so that the first dielectric layer comprises a first gate dielectric region disposed below and defined by the first dummy gate structure. A first spacer element is formed on a portion of the first dielectric layer, and the first spacer element abuts the first dummy gate structure, and the portion of the first dielectric layer comprises a first spacer dielectric region disposed below and defined by the first spacer element. A first recessed portion is formed in the substrate. A strained material is selectively grown over the first recessed portion of the substrate to form a first strained recessed region, and the first strained recess region is adjacent the first spacer dielectric region. The first dummy gate structure is removed. A second dielectric layer is formed on the first gate dielectric region. The second dielectric layer and the first gate dielectric region are removed to form a first opening. A first gate structure including a gate electrode layer and a gate dielectric layer is formed in the first opening.

[0059] In accordance with another aspect of the present disclosure, a semiconductor device includes a first structure and a second structure. The first structure includes a first gate structure disposed over a substrate, a first spacer element abutting the first gate structure and a first strained recess region over a recessed portion in the substrate adjacent the first gate structure. The second structure includes a second gate structure disposed over the substrate, a second spacer element abutting the second gate structure and a second strained recess region over a recessed portion in the substrate adjacent the second gate structure. The first gate structure includes a first gate dielectric region disposed over the substrate and underlying a first gate electrode. The second gate structure includes a second gate dielectric region disposed over the substrate and underlying a second gate electrode. A first spacer dielectric region is disposed over the substrate and underlying the first spacer element and a second spacer dielectric region is disposed over the substrate and underlying the second spacer element. A height of the second gate dielectric region is greater than the height of the second spacer dielectric region.

[0060] The foregoing outlines features of several embodiments or examples 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 or examples 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 semiconductor device comprising: a first channel region; a first source/drain epitaxial layer adjacent a sidewall of the channel region; a dielectric layer disposed over the first source/drain epitaxial layer; an interfacial dielectric layer disposed on the first channel region; a gate dielectric layer disposed on the interfacial dielectric layer; a gate electrode disposed over the first gate dielectric layer; a first gate sidewall spacer disposed over a sidewall of the first gate electrode; and a first spacer dielectric layer disposed between the first gate sidewall spacer and the first channel region, wherein a width of the first spacer dielectric layer equals a width of the first gate sidewall spacer, and the interfacial dielectric layer is separated from the first source/drain epitaxial layer by the first spacer dielectric layer.
2. The semiconductor device of claim 1, wherein the first spacer dielectric layer is made of silicon oxide.
3. The semiconductor device of claim 2, wherein the first gate dielectric layer includes a high-k

dielectric material.

4. The semiconductor device of claim 1, wherein the first gate sidewall spacer includes multiple layers.

5. The semiconductor device of claim 4, wherein the first gate sidewall spacer comprises three layers.

6. The semiconductor device of claim 1, wherein the first spacer dielectric layer is flush with the first gate sidewall spacer.

7. The semiconductor device of claim 1, wherein: the semiconductor device further includes a gate sidewall spacer disposed over the first gate sidewall spacer.

8. The semiconductor device of claim 1, further comprising a second source/drain epitaxial layer disposed on an opposing side of the first channel region from the first source/drain epitaxial layer.

9. A semiconductor device including a field effect transistor (FET), the FET comprising: an active region comprising a channel region and a source/drain region disposed over a substrate, wherein the channel region and the source/drain region are disposed over the substrate along a first direction and the channel region and the source/drain region are arranged along a second direction crossing the first direction; a gate structure disposed over the channel region; a first gate sidewall spacer disposed along a sidewall of the gate structure, wherein the gate structure comprises a high-k gate dielectric layer and a gate electrode disposed over the high-k gate dielectric layer; and a spacer dielectric layer disposed between the first gate sidewall spacer and the channel region, wherein a surface of the spacer dielectric layer furthest from the substrate along the first direction is located at different distance from the substrate than a surface of the high-k gate dielectric layer closest to the substrate along the first direction.

10. The semiconductor device of claim 9, wherein the source/drain region comprises a first source/drain region and a second source/drain region disposed on opposing sides of the channel region along the second direction.

11. The semiconductor device of claim 9, wherein a surface of the spacer dielectric layer closest to the substrate along the first direction is located at a different distance from the substrate than a surface of the high-k gate dielectric layer closest to the substrate along the first direction.

12. The semiconductor device of claim 9, further comprising an interfacial dielectric layer disposed between the high-k gate dielectric layer and the channel region.

13. The semiconductor device of claim 9, wherein the surface of the spacer dielectric layer furthest from the substrate along the first direction is flush with the first gate sidewall spacer.

14. The semiconductor device of claim 9, wherein the first gate sidewall spacer includes multiple layers.

15. The semiconductor device of claim 9, wherein a width of the spacer dielectric layer along the second direction equals a width of the first gate sidewall spacer along the second direction.

16. The semiconductor device of claim 9, wherein the high-k gate dielectric layer has a U-shape cross section.

17. A semiconductor device comprising: a field effect transistor (FET) disposed over a substrate; wherein the FET includes: a channel region; a source/drain epitaxial layer and a second source/drain epitaxial layer disposed on opposing sides of the channel region along a first direction; a gate structure disposed over the channel region along a second direction crossing the first direction, wherein the gate structure includes an interfacial dielectric layer disposed over the channel region, a gate dielectric layer disposed over the interfacial dielectric layer, and a gate electrode layer disposed over the gate dielectric layer; a gate sidewall spacer disposed along sidewalls of the gate electrode layer; and a spacer dielectric layer disposed between the gate sidewall spacer and the channel region, wherein the interfacial dielectric layer and the gate dielectric layer are made of different materials, and a plane of an uppermost surface of the spacer dielectric layer extending along the first direction is spaced apart along the second direction from a plane of a lowermost surface of the gate dielectric layer extending along the first direction.

18. The semiconductor device of claim 17, wherein the gate dielectric layer has a U-shape cross section.

19. The semiconductor device of claim 17, wherein the gate dielectric layer is made of a high-k material.

20. The semiconductor device of claim 17, wherein the spacer dielectric layer is flush with the gate sidewall spacer.
