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(54) **METHOD FOR MANUFACTURING A SEMICONDUCTOR DEVICE USING A NITROGEN CONTAINING OXIDE LAYER**

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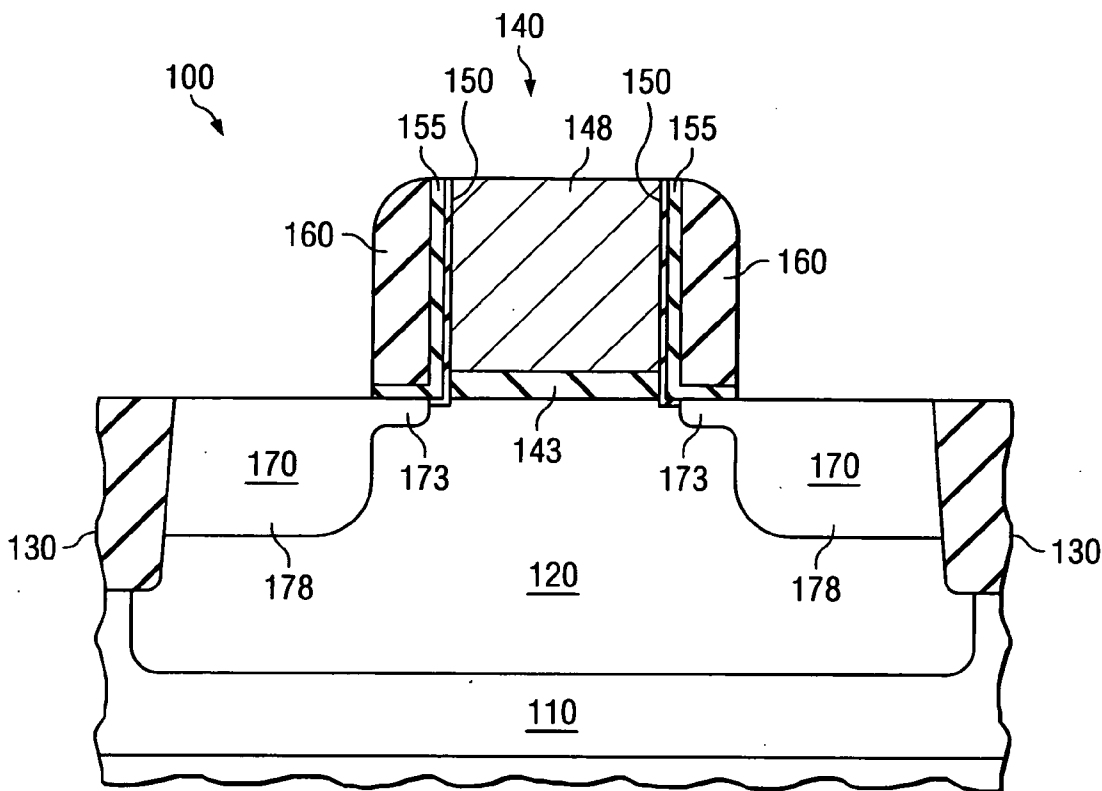
(57) **ABSTRACT**

The present invention provides a method for forming a semiconductor device, as well as a semiconductor device. The method for manufacturing a semiconductor device, among others, includes providing a gate structure over a substrate, the gate structure including a gate electrode located over a nitrided gate dielectric, and forming a nitrided region over a sidewall of the nitrided gate dielectric.

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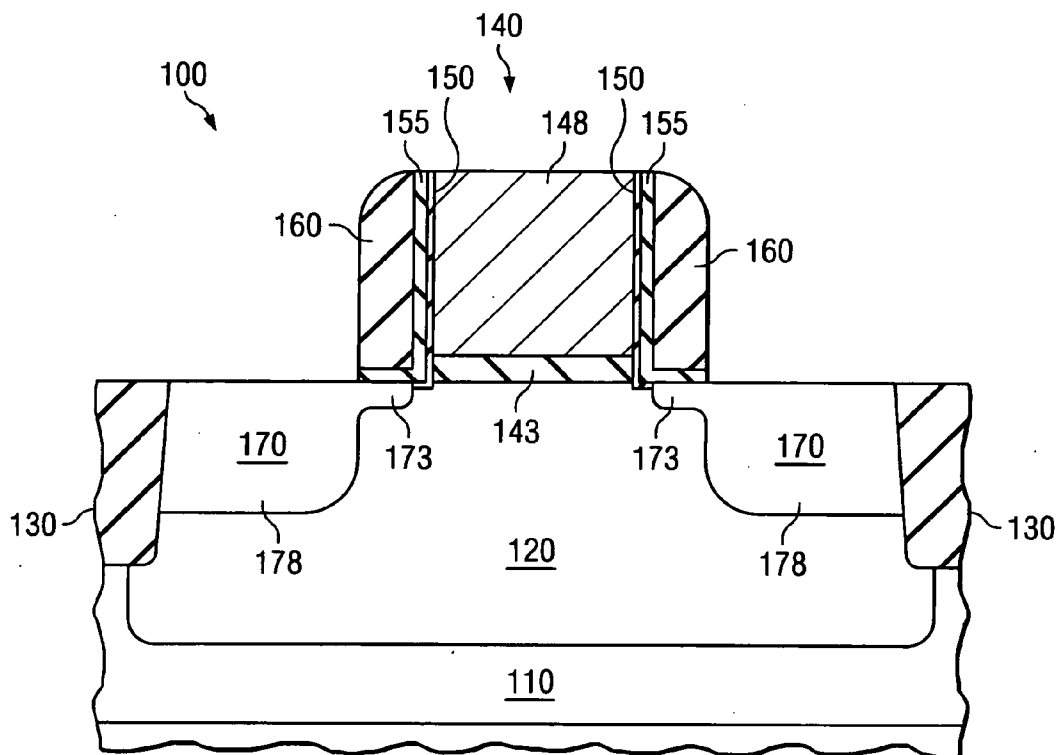


FIG. 1

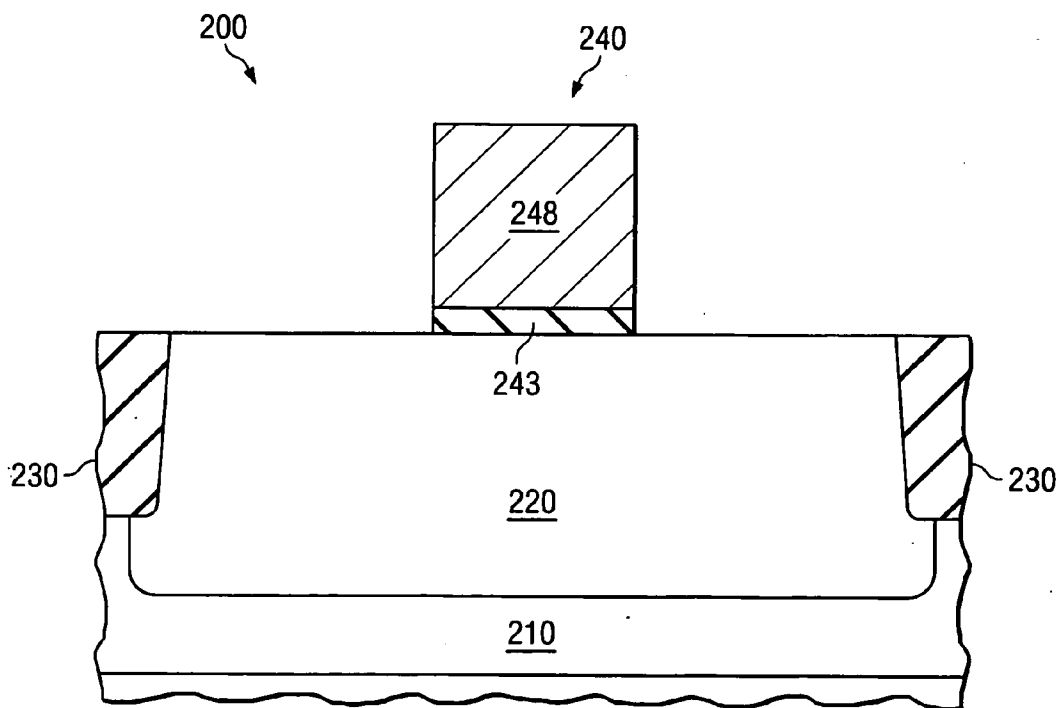


FIG. 2

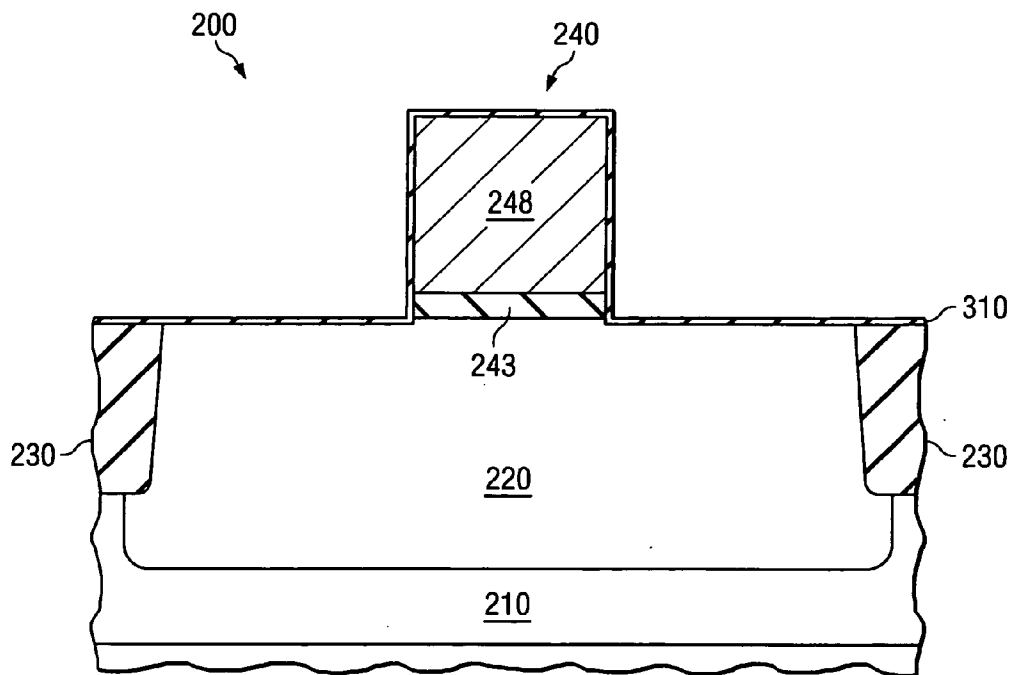


FIG. 3

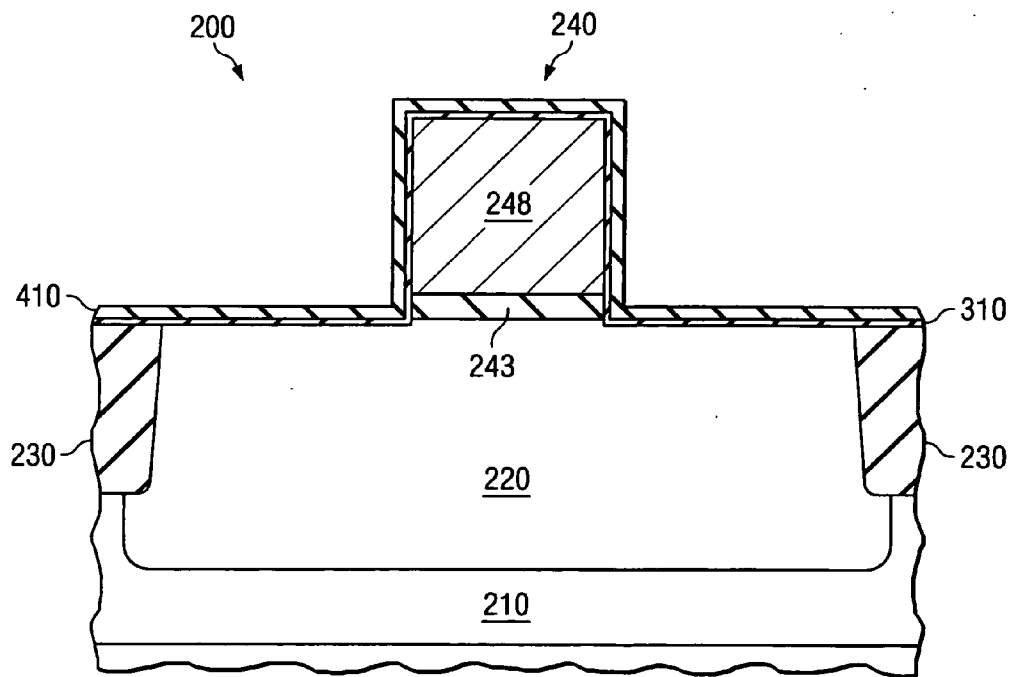


FIG. 4

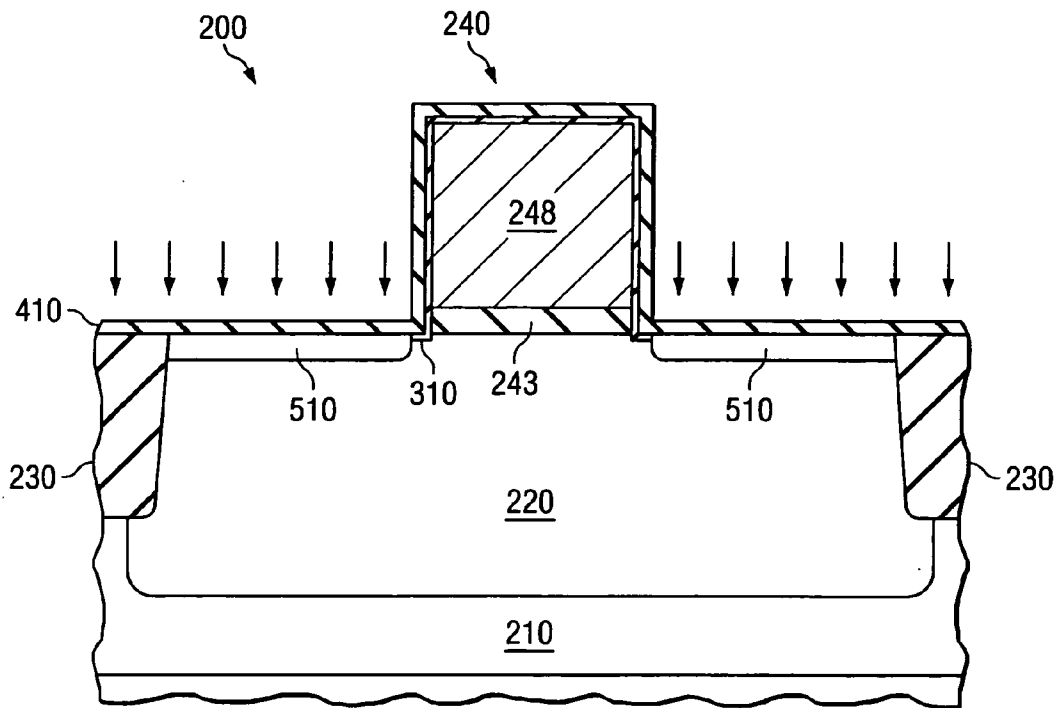


FIG. 5

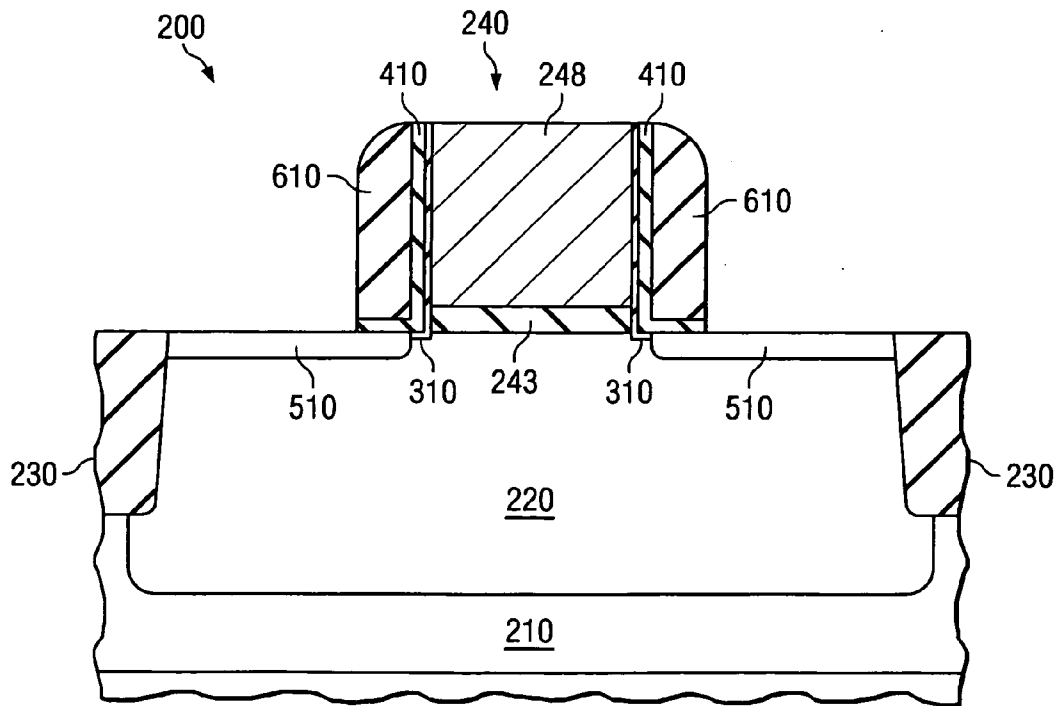


FIG. 6

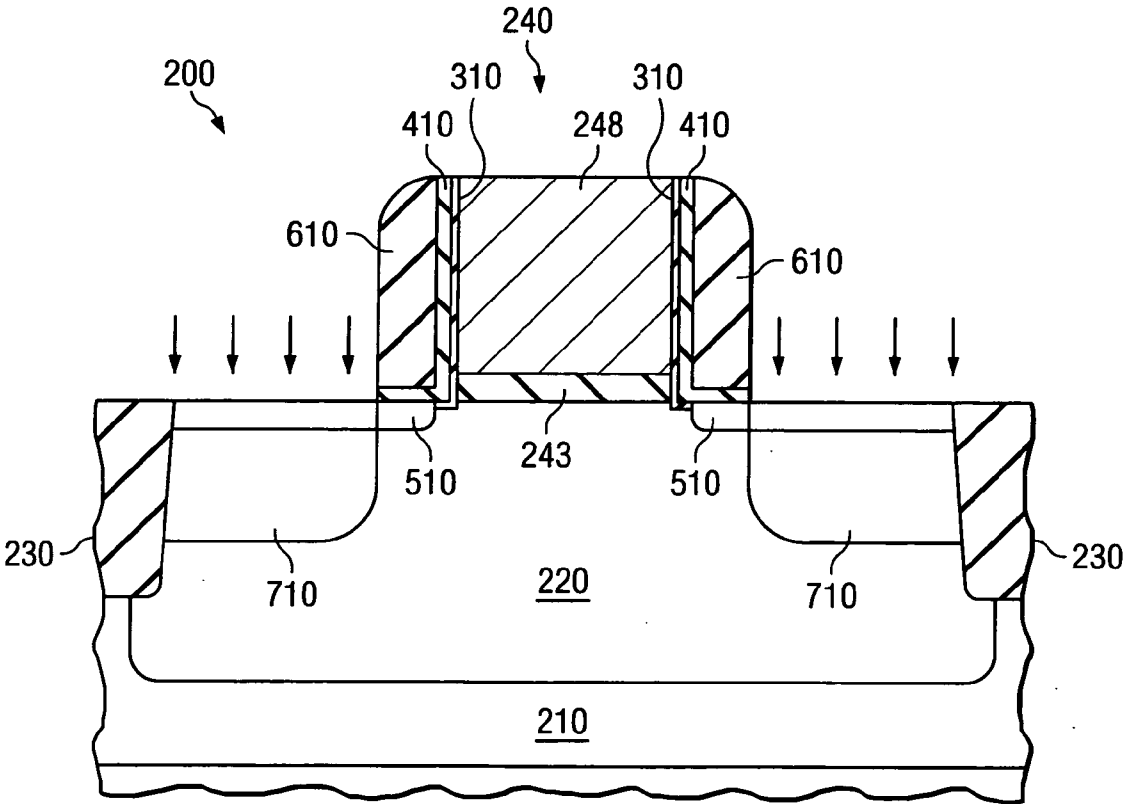


FIG. 7

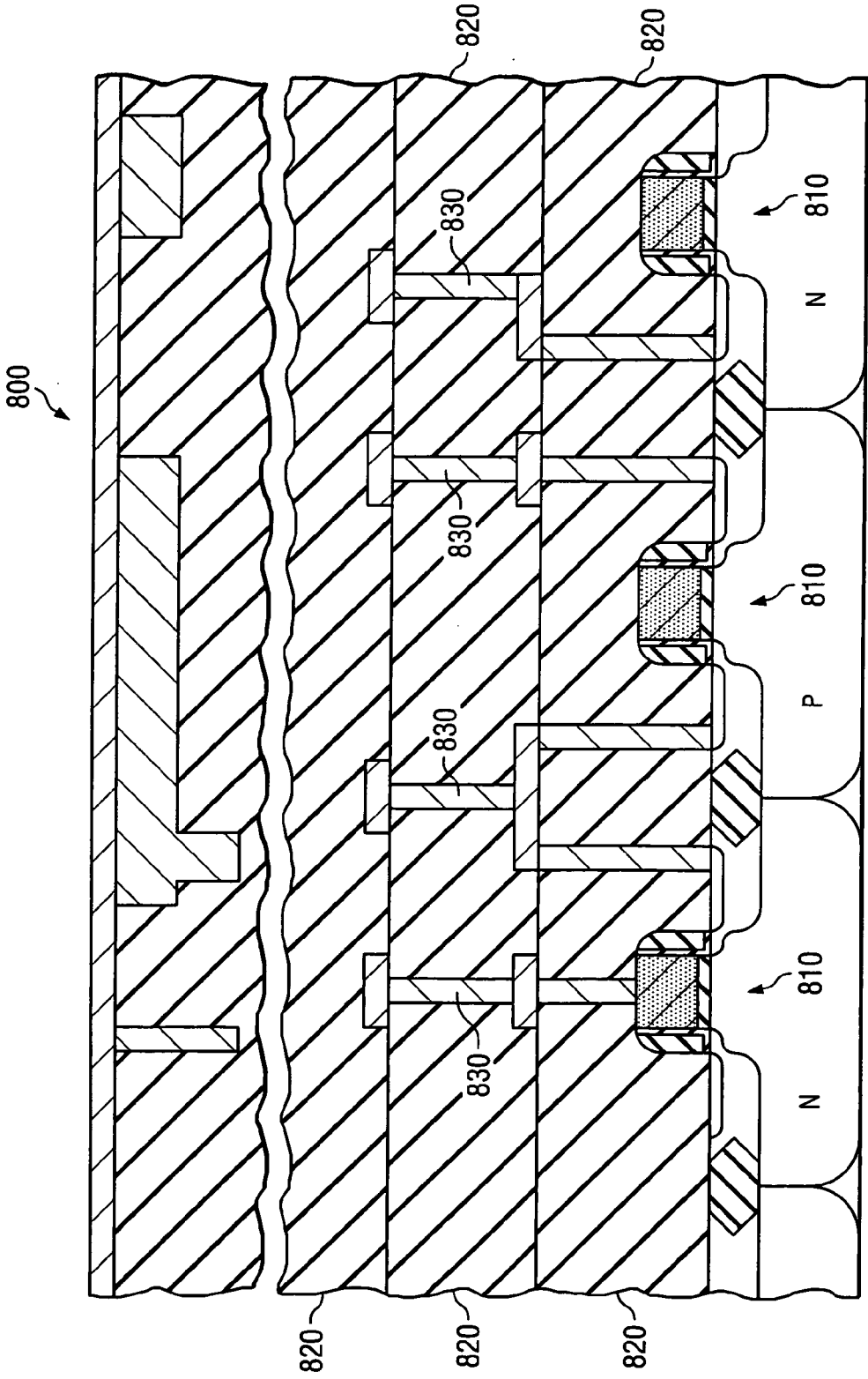


FIG. 8

METHOD FOR MANUFACTURING A SEMICONDUCTOR DEVICE USING A NITROGEN CONTAINING OXIDE LAYER

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention is directed, in general, to a method for manufacturing a semiconductor device and, more specifically, to a method for manufacturing a semiconductor device using a nitrogen containing oxide layer.

BACKGROUND OF THE INVENTION

[0002] The trend in semiconductor technology to double the functional complexity of its products every 18 months (e.g., Moore's "law") has several implicit consequences. First, the cost per functional unit should drop with each generation of complexity so that the cost of the product with its doubled functionality would increase only slightly. Second, the higher product complexity should largely be achieved by shrinking the feature sizes of the chip components while holding the package dimensions constant; preferably, even the package dimensions should shrink. And third, but not least, the increased functional complexity should be paralleled by an equivalent increase in reliability of the product.

[0003] The scaling of the components in the lateral dimension requires vertical scaling as well, so as to achieve adequate device performance. This vertical scaling requires the thickness of the gate dielectric, commonly silicon dioxide, to be reduced. Thinning of the silicon dioxide gate dielectric provides a smaller barrier to dopant diffusion from a polysilicon gate structure (or metal diffusion from a metal gate structure) through the underlying dielectric, often resulting in devices with diminished electrical performance (e.g., leakage) and reliability.

[0004] One well-established technique for mitigating the problems associated with silicon dioxide gate dielectrics includes using a nitrided gate dielectric (e.g., for example a silicon oxynitride gate dielectric, nitrided high-k dielectric, nitrided silicate gate dielectric, etc.) to raise the dielectric constant thereof. This allows the use of a thicker gate dielectric where a thinner dielectric would ordinarily be needed, providing for less leakage through the gate dielectric. Unfortunately, nitrided gate dielectrics are susceptible to having non-uniform nitrogen profiles therein, which negatively affect the reliability thereof.

[0005] Accordingly, what is needed in the art is a semiconductor device having a nitrided gate dielectric layer therein, as well as a method of manufacture therefore, which do not experience the drawbacks of the prior art.

SUMMARY OF THE INVENTION

[0006] To address the above-discussed deficiencies of the prior art, the present invention provides a method for forming a semiconductor device, as well as a semiconductor device. The method for manufacturing a semiconductor device, among others, includes providing a gate structure over a substrate, the gate structure including a gate electrode located over a nitrided gate dielectric, and forming a nitride region in a sidewall of the nitrided gate dielectric.

[0007] Another embodiment of the present invention is a semiconductor device. The semiconductor device includes a

gate structure positioned over a substrate, the gate structure including a gate electrode located over a nitrided gate dielectric, and a nitride region located in a sidewall of the nitrided gate dielectric.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] For a more complete understanding of the present invention, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

[0009] FIG. 1 illustrates a sectional view of a semiconductor device manufactured in accordance with the principles of the present invention;

[0010] FIGS. 2-7 illustrates sectional views illustrating how one might, in an advantageous embodiment, manufacture a semiconductor device similar to the semiconductor device depicted in FIG. 1; and

[0011] FIG. 8 illustrates a sectional view of an integrated circuit (IC) incorporating semiconductor devices constructed according to the principles of the present invention.

DETAILED DESCRIPTION

[0012] The present invention is based, at least in part, on the recognition that the conventional formation of an oxide liner (e.g., poly-Si oxidation and smile oxidation) surrounding the gate electrode and nitrided gate dielectric layer of a gate structure tends to change the doping profile of the nitrogen located within the nitrided gate dielectric layer. The present invention has particularly recognized that the conventional formation of the oxide liner decreases the nitrogen concentration profile at the edge, as compared to the center of the nitrided gate dielectric layer.

[0013] Given these recognitions, the present invention acknowledges that a nitrogen containing oxide layer, alone or in combination with a nitride region in the sidewall of the nitrided gate dielectric layer, can be used to improve the uniformity of the nitrogen across a length of the nitrided gate dielectric layer. Without this nitrogen containing oxide layer, whether recognized in the art or not, the nitrided gate dielectric layer would have lower amounts of nitrogen at its edge than center.

[0014] Turning now to FIG. 1, illustrated is a sectional view of a semiconductor device 100 manufactured in accordance with the principles of the present invention. The semiconductor device 100 initially includes a substrate 110. Located within the substrate 110 in the embodiment of FIG. 1 is a well region 120, and isolation structures 130. The well region 120 and isolation structures 130 may be conventional features.

[0015] Additionally located over the substrate 110 and well region 120 is a gate structure 140. The gate structure 140 illustrated in FIG. 1 includes a nitrided gate dielectric 143 located over the substrate 110, as well as a gate electrode 148 located over the nitrided gate dielectric 143. Those skilled in the art appreciate the various different types of materials that the gate electrode 148 and nitrided gate dielectric 143 may comprise. For example, while the nitrided gate dielectric 143 illustrated in FIG. 1 comprises a silicon oxynitride gate dielectric, other nitrogen containing dielectrics, such as nitrided high-K dielectrics, nitrided

silicate gate dielectrics, etc., may be used. Those skilled in the art further appreciate that the thicknesses of each of the nitrided gate dielectric **143** and gate electrode **148** may vary according to the design rules of the semiconductor device **100**.

[0016] Located in the sidewall of the nitrided gate dielectric **143** is a nitride region **150**. In the embodiment of FIG. 1, the nitride region **150** is actually located along all of the sidewalls of the nitrided gate dielectric **143** as well as along all of the sidewalls of the gate electrode **148**. The nitride region **150** may embody a number of different thicknesses. However, one particular embodiment uses a nitride region **150** thickness ranging from about 0.5 nm to about 1.0 nm. Other thicknesses nevertheless might be used.

[0017] The nitride region **150**, in one embodiment, contains a sufficient amount of nitrogen therein to reduce the aforementioned drop-off in the nitrogen profile at the edge of the nitrided gate dielectric **143**. For example, in one embodiment the nitride region **150** contains from about 5 atomic percent to about 10 atomic percent of nitrogen therein. However, the present invention should not be limited to any specific amount of nitrogen. Accordingly, edges of the nitrided gate dielectric **143** may ultimately have substantially the same concentration of nitrogen that a center of the nitrided gate dielectric **143** would have. Alternatively, the amount of nitrogen in the nitride region **150** may be such that the edges of the nitrided gate dielectric **143** have a higher amount of nitrogen than a center of the nitrided gate dielectric **143** would have.

[0018] Positioned over the nitride region **150** is a nitrogen containing oxide layer **155**. In the embodiment shown, the nitrogen containing oxide layer **155** is located along all of the sidewalls of the nitrided gate dielectric **143** as well as along all of the sidewalls of the gate electrode **148**. Accordingly, the nitride region **150** of FIG. 1 completely separates the nitrogen containing oxide layer **155** from the nitrided gate dielectric **143** and gate electrode **148**. Similar to the nitride region **150**, the nitrogen containing oxide layer **155** may embody a number of different thicknesses. However, one particular embodiment uses a nitrogen containing oxide layer **155** thickness ranging from about 1.0 nm to about 1.5 nm. Other thicknesses nevertheless might be used.

[0019] The gate structure **140** further contains gate sidewall spacers **160** located on both sides of the nitrided gate dielectric **143** and gate electrode **148**. While the gate sidewall spacers **160** of FIG. 1 include only a single anisotropically etched oxide or nitride portion, other embodiments exist wherein the gate sidewall spacers each include a number of different layers.

[0020] Thus, the gate sidewall spacers **160** may comprise many different types and numbers of layers while staying consistent with the principles of the present invention.

[0021] The semiconductor device **100** illustrated in FIG. 1 additionally includes source/drain regions **170** located within the substrate **110** and proximate the nitrided gate dielectric **143**. The source/drain regions **170** may be conventional. Accordingly, in one embodiment the source/drain regions **170** each include an extension portion **173** and a heavier doped portion **178**.

[0022] Turning now to FIGS. 2-7, illustrated are sectional views illustrating how one might, in an advantageous

embodiment, manufacture a semiconductor device similar to the semiconductor device **100** depicted in FIG. 1. FIG. 2 illustrates a sectional view of a partially completed semiconductor device **200** manufactured in accordance with the principles of the present invention. The semiconductor device **200** of FIG. 2 includes a substrate **210**. The substrate **210** may, in an exemplary embodiment, be any layer located in the semiconductor device **200**, including a wafer itself or a layer located above the wafer (e.g., epitaxial layer). In the embodiment illustrated in FIG. 2, the substrate **210** is a P-type substrate; however, one skilled in the art understands that the substrate **210** could be an N-type substrate without departing from the scope of the present invention. In such a case, each of the dopant types described throughout the remainder of this document would be reversed. For clarity, no further reference to this opposite scheme will be discussed.

[0023] Located within the substrate **210** in the embodiment shown in FIG. 2 is a well region **220**. The well region **220**, in light of the P-type semiconductor substrate **210**, should generally contain an N-type dopant. For example, the well region **220** would likely be doped with an N-type dopant dose ranging from about $1E13$ atoms/cm² to about $1E14$ atoms/cm² and at an energy ranging from about 100 keV to about 500 keV. This results in the well region **220** having a peak dopant concentration ranging from about $5E17$ atoms/cm³ to about $1E19$ atoms/cm³.

[0024] Located within the substrate **210** proximate the well region **220** are isolation structures **230**. The isolation structures **230** are generally used to isolate the semiconductor device **200** illustrated in FIG. 2 from other devices located proximate thereto. In the embodiment of FIG. 2, the isolation structures **230** are shallow trench isolation structures. However, those skilled in the art appreciate that other isolation structures, such as field oxide isolation structures, etc., may also be used.

[0025] Located over the substrate **210** in the embodiment of FIG. 2 is a gate structure **240**. The gate structure **240** includes a nitrided gate dielectric **243** and a gate electrode **248**. The nitrided gate dielectric **243** may comprise a number of different thicknesses and stay within the scope of the present invention. In the illustrative embodiment of FIG. 2, however, the nitrided gate dielectric **243** has a thickness ranging from about 0.5 nm to about 5 nm.

[0026] The nitrided gate dielectric **243** may, again, comprise many different nitrogen containing gate dielectric materials.

[0027] For example, the nitrided gate dielectric **243** may comprise a silicon oxynitride gate dielectric, a nitrided high-k gate dielectric, a nitrided silicate gate dielectric, among others. In the embodiment of FIGS. 2-7, however, the nitrided gate dielectric **243** comprises a silicon oxynitride gate dielectric.

[0028] Any one of a plurality of manufacturing techniques could be used to form the nitrided gate dielectric **243**. In the example wherein the nitrided gate dielectric **243** is a silicon oxynitride gate dielectric, such as shown in FIGS. 2-7, the silicon oxynitride gate dielectric could be formed by first growing or depositing a silicon dioxide gate dielectric layer, and thereafter subjecting the silicon dioxide gate dielectric layer to a nitrogen containing plasma source to introduce the

nitrogen into the silicon dioxide gate dielectric layer. However, those skilled in the art of silicon oxynitride gate dielectrics would understand the other processes, conventional or not, that might be used to form the silicon oxynitride gate dielectric.

[0029] The gate electrode **248**, in one embodiment, may comprise a conventional polysilicon gate electrode. Alternatively, however, the gate electrode **248** might comprise an amorphous polysilicon gate electrode, or even possibly a partially or fully silicided gate electrode or metal gate electrode. Accordingly, the present invention should not be limited to any specific gate electrode material.

[0030] In the embodiment wherein the gate electrode **248** comprises a polysilicon gate electrode, the polysilicon gate electrode could be deposited using a pressure ranging from about 100 torr to about 300 torr, a temperature ranging from about 620° C. to about 700° C., and a SiH₄ or Si₂H₆ gas flow ranging from about 50 sccm to about 150 sccm. If, however, amorphous polysilicon were desired, the amorphous polysilicon gate electrode could be deposited using a pressure ranging from about 100 torr to about 300 torr, a temperature ranging from about 450° C. to about 550° C., and a SiH₄ or Si₂H₆ gas flow ranging from about 100 sccm to about 300 sccm. In any instance, the gate electrode **248** desirably has a thickness ranging from about 50 nm to about 150 nm.

[0031] Turning now to FIG. 3, illustrated is a sectional view of the semiconductor device **200** of FIG. 2 after forming a nitride region **310** in a sidewall of the nitrided gate dielectric **243**. In the given embodiment of FIG. 3, the nitride region **310** is not only formed in the sidewall of the nitrided gate dielectric **243**, but is formed entirely along the sidewalls of the nitrided gate dielectric **243**, entirely along the sidewalls of the gate electrode **248**, and along the exposed upper surface of the substrate **210**. Accordingly, the nitride region **310** of FIG. 3 is somewhat of a conformal nitride region. The nitride region **310**, in accordance with the principles of the present invention, would generally have a thickness ranging from about 0.5 nm to about 1.0 nm, and a nitrogen concentration ranging from about 5 atomic percent to about 10 atomic percent. Other thicknesses and nitrogen concentrations could nonetheless also be used and remain within the purview of the present invention.

[0032] The nitride region **310** may be formed using various different processes. In one embodiment, the nitride region **310** is formed by subjecting the semiconductor device **200** to a nitrogen containing plasma. For instance, the nitrogen containing plasma might be a pulse RF plasma using a flow rate of nitrogen gas ranging from about 50 sccm to about 100 sccm, a pressure ranging from about 20 mTorr to about 40 mTorr, an RF power ranging from about 800 Watts to about 1200 Watts, a duty cycle (e.g., the ratio of the sum of all pulse durations during a specified period of continuous operation to the total specified period of operation) ranging from about 5% to about 10%, a pulse frequency ranging from about 0.5 kHz to 1.5 kHz, for a time period ranging from about 5 seconds to about 15 seconds. Alternatively, the nitrogen containing plasma might be a microwave plasma using a flow rate of nitrogen gas ranging from about 100 sccm to about 300 sccm, a flow rate of an inert gas (e.g., argon) ranging from about 1000 sccm to about 2000 sccm, a pressure ranging from about 500 mTorr to about 2 Torr, a microwave power ranging from about 500

Watts to about 1500 Watts, at a temperature ranging from about 200° C. to about 500° C., for a time period ranging from about 5 seconds to about 15 seconds. Other conditions outside of the aforementioned ranges could also be used.

[0033] After completing the formation of the nitride region **310**, the nitride region **310**, and more particularly the nitrided gate dielectric **243** and gate electrode **248**, may be subjected to a reoxidation step. The reoxidation step is configured to remove damage, particularly plasma damage, which may have been caused during the formation of the nitride region **310**. In one embodiment, the reoxidation step is a low-temperature reoxidation process. For example, the low temperature reoxidation process might include subjecting the semiconductor device **200** to about 1% to about 50% oxygen gas (O₂) in nitrogen gas (N₂) for a time period ranging from about 30 seconds to about 60 seconds, in the presence of a pressure ranging from about 700 Torr to about 800 Torr and a temperature ranging from about 400° C. to about 600° C. However, other processing conditions could also be used.

[0034] Turning now to FIG. 4, illustrated is a sectional view of the semiconductor device **200** of FIG. 3 after forming a nitrogen containing oxide layer **410** over a sidewall of the nitrided gate dielectric **243**. In the given embodiment of FIG. 4, the nitrogen containing oxide layer **410** is not only formed over the sidewall of the nitrided gate dielectric **243**, but is formed entirely along the sidewalls of the nitrided gate dielectric **243**, entirely along the sidewalls of the gate electrode **248**, and along the exposed upper surface of the substrate **210**, the nitride region **310** separating the nitrogen containing oxide layer **410** from each of those layers.

[0035] Accordingly, the nitrogen containing oxide layer **410** of FIG. 4 is also somewhat of a conformal layer. The nitrogen containing oxide layer **410**, in accordance with the principles of the present invention, would generally have a thickness ranging from about 1.0 nm to about 1.5 nm. Other thicknesses could nonetheless also be used and remain within the purview of the present invention.

[0036] The nitrogen containing oxide layer **410** may be formed using various different processes. However, in one embodiment the nitrogen containing oxide layer **410** is formed by the oxynitridation of the nitride region **310** in the presence of a nitrogen containing gas. For instance, the oxynitridation might occur in the presence of nitrous oxide (N₂O) gas or nitric oxide (NO) gas or its mixtures, among others. The formation of the oxide layer might occur in the presence of a temperature ranging from about 700° C. to about 1000° C., a pressure ranging from about 50 Torr to about 500 Torr, for a time period ranging from about 30 seconds to about 60 seconds. Other conditions outside of the aforementioned ranges could also be used, as well as the nitrogen containing oxide layer **410** might be deposited in an alternative embodiment. The resulting stack of the nitride region **310** and the nitrogen containing oxide layer **410** should, desirably, have a thickness ranging from about 1.5 nm to about 2.5 nm.

[0037] Turning now to FIG. 5, illustrated is a sectional view of the semiconductor device **200** illustrated in FIG. 4 after formation of extension implants **510** within the substrate **210**. The extension implants **510** may be conventionally formed and generally have a peak dopant concentration

ranging from about $1E19$ atoms/cm³ to about $2E20$ atoms/cm³. As is standard in the industry, the extension implants **510** have a dopant type opposite to that of the well region **220** they are located within. Accordingly, the extension implants **510** are doped with a P-type dopant in the illustrative embodiment shown in FIG. 5.

[0038] Turning now to FIG. 6, illustrated is a sectional view of the semiconductor device **200** illustrated in FIG. 5 after forming gate sidewall spacers **610**. In the given embodiment of FIG. 6, the gate sidewall spacers **610** comprise an oxide. For example, a blanket oxide layer may be deposited, and then subjected to an anisotropic etch, thereby resulting in the gate sidewall spacers **610**, nitride region **310**, and nitrogen containing oxide layer **410** illustrated in FIG. 6. Nevertheless, the gate sidewall spacers **610** may comprise other materials, as well as be forming using other processes than disclosed above.

[0039] Turning now to FIG. 7, illustrated is a sectional view of the semiconductor device **200** of FIG. 6 after forming highly doped source/drain implants **710** within the substrate **210**. The formation of the highly doped source/drain implants **710** may be conventional. Generally the highly doped source/drain implants **710** have a peak dopant concentration ranging from about $1E18$ atoms/cm³ to about $1E21$ atoms/cm³. Also, the highly doped source/drain implants **710** should typically have a dopant type opposite to that of the well region **220** they are located within. Accordingly, in the illustrative embodiment shown in FIG. 7, the highly doped source/drain implants **710** are doped with a P-type dopant.

[0040] After formation of the highly doped source/drain implants **710**, the semiconductor device **200** may be subjected to a standard source/drain anneal, thereby activating source/drain regions. It is believed that a source/drain anneal conducted at a temperature ranging from about 1000° C. to about 1100° C. and a time period ranging from about 1 second to about 5 seconds would be sufficient. It should be noted that other temperatures, times, and processes could be used to activate the source/drain regions. What results, at least after various other well-known processing steps, is a semiconductor device substantially similar to the semiconductor device **100** shown and discussed with respect to FIG. 1.

[0041] It should be noted that the exact order of the steps illustrated with respect to FIGS. 2-7 may change depending on the process flow. Additionally, various other steps could be added to the description of FIGS. 2-7. Accordingly, the present invention should not be limited by the disclosures made above with respect to FIGS. 2-7.

[0042] The method of manufacturing the semiconductor device as discussed with respect to FIGS. 2-7 provides many benefits over the prior art methods. First, and possibly most important, it improves transistor performance as critical dimensions (CD) and poly oxide thickness is scaled, for example by reducing nitrogen atom loss from the edge of the nitrided gate dielectric. Additionally, the process flow according to the present invention is compatible with conventional process flows. Moreover, the idea can be integrated into a single cluster tool.

[0043] Referring finally to FIG. 8, illustrated is a sectional view of an integrated circuit (IC) **800** incorporating semi-

conductor devices **810** constructed according to the principles of the present invention. The IC **800** may include devices, such as transistors used to form CMOS devices, BiCMOS devices, Bipolar devices, as well as capacitors or other types of devices. The IC **800** may further include passive devices, such as inductors or resistors, or it may also include optical devices or optoelectronic devices. Those skilled in the art are familiar with these various types of devices and their manufacture. In the particular embodiment illustrated in FIG. 8, the IC **800** includes the semiconductor devices **810** having dielectric layers **820** located thereover. Additionally, interconnect structures **830** are located within the dielectric layers **820** to interconnect various devices, thus, forming the operational integrated circuit **800**.

[0044] Although the present invention has been described in detail, those skilled in the art should understand that they can make various changes or substitutions herein without departing from the spirit and scope of the invention in its broadest form.

What is claimed is:

1. A method for manufacturing a semiconductor device, comprising:

providing a gate structure over a substrate, the gate structure including a gate electrode located over a nitrided gate dielectric; and

forming a nitride region in a sidewall of the nitrided gate dielectric.

2. The method as recited in claim 1 wherein forming a nitride region includes subjecting the sidewall to a nitrogen containing plasma.

3. The method as recited in claim 2 wherein the nitrogen containing plasma uses an RF plasma or a microwave plasma.

4. The method as recited in claim 1 wherein forming a nitride region in the sidewall further includes forming a nitride region in sidewalls of the gate electrode.

5. The method as recited in claim 1 further including subjecting the nitride region to a reoxidation step prior to forming a nitrogen containing oxide layer thereover.

6. The method as recited in claim 5 wherein the reoxidation step uses a temperature ranging from about 400° C. to about 600° C. for a time period ranging from about 30 seconds to about 60 seconds.

7. The method as recited in claim 1 further including forming a nitrogen containing oxide layer over the nitride region.

8. The method as recited in claim 7 wherein forming the nitrogen containing oxide layer includes forming the nitrogen containing oxide layer by the oxynitridation of the nitride region in the presence of a nitrogen containing gas.

9. The method as recited in claim 8 wherein the nitrogen containing gas is nitrous oxide (N₂O) or nitric oxide (NO) or its mixtures.

10. The method as recited in claim 7 wherein forming the nitrogen containing oxide layer over the nitride region further includes forming the nitrogen containing oxide layer over sidewalls of the gate electrode.

11. The method as recited in claim 1 further including forming a dielectric layer having interconnects therein over the gate structure to form an operational integrated circuit.

- 12.** A semiconductor device, comprising:
a gate structure positioned over a substrate, the gate structure including a gate electrode located over a nitrided gate dielectric; and
a nitride region located in a sidewall of the nitrided gate dielectric.
- 13.** The semiconductor device as recited in claim 12 wherein the nitride region has a thickness ranging from about 0.5 nm and about 1.0 nm.
- 14.** The semiconductor device as recited in claim 12 wherein the nitride region is further located in sidewalls of the gate electrode.
- 15.** The semiconductor device as recited in claim 12 further including a nitrogen containing oxide layer located over the nitride region.
- 16.** The semiconductor device as recited in claim 15 wherein the nitrogen containing oxide layer is further located over sidewalls of the gate electrode.

17. The semiconductor device as recited in claim 15 wherein the nitrogen containing oxide layer has a thickness ranging from about 1.0 nm to about 1.5 nm.

18. The semiconductor device as recited in claim 12 wherein edges of the nitrided gate dielectric have a higher concentration of nitrogen than a center of the nitrided gate dielectric.

19. The semiconductor device as recited in claim 12 wherein edges of the nitrided gate dielectric have substantially the same concentration of nitrogen than a center of the nitrided gate dielectric.

20. The semiconductor device as recited in claim 12 further including a dielectric layer having interconnects therein located over the gate structure.

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