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(54) PMOS TRANSISTOR STRAIN OPTIMIZATION WITH RAISED JUNCTION REGIONS

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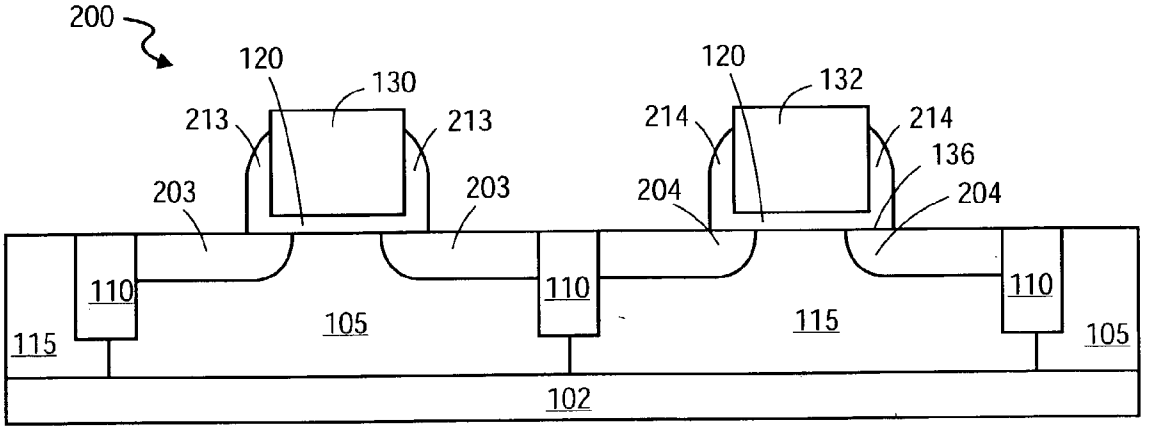
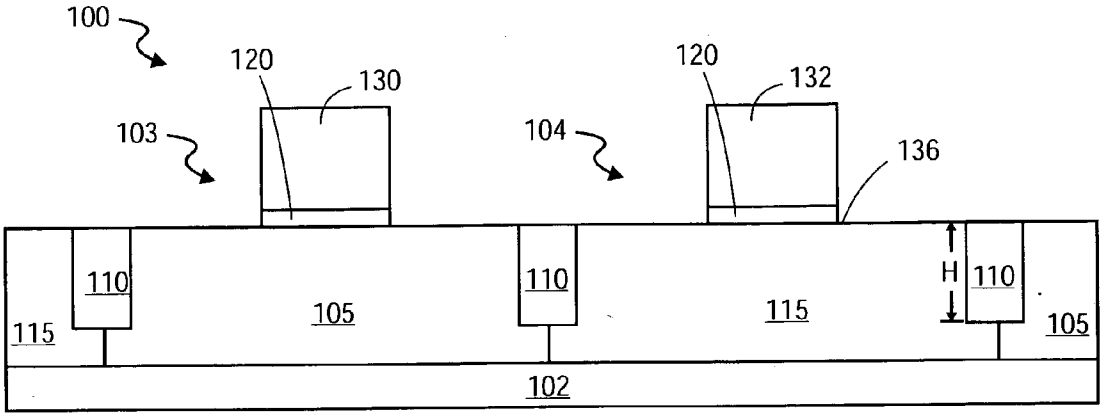
(57) **ABSTRACT**

Optimal strain in the channel region of a PMOS transistor is provided by silicon alloy material in the junction regions of the device in a non-planar relationship with the surface of the substrate. The silicon alloy material, the dimensions of the silicon alloy material, as well as the non-planar relationship of the silicon alloy material with the surface of the substrate are selected so that the difference between the lattice spacing of the silicon alloy material and of the substrate causes strains in the silicon alloy material below the substrate surface, as well as above the substrate surface, to affect an optimal silicon alloy induced strain in the substrate channel. In addition, the non-planar relationship may be selected so that any strains caused by different lattice spaced layers formed over the silicon alloy material have a reduced effect on the strain in the channel region.

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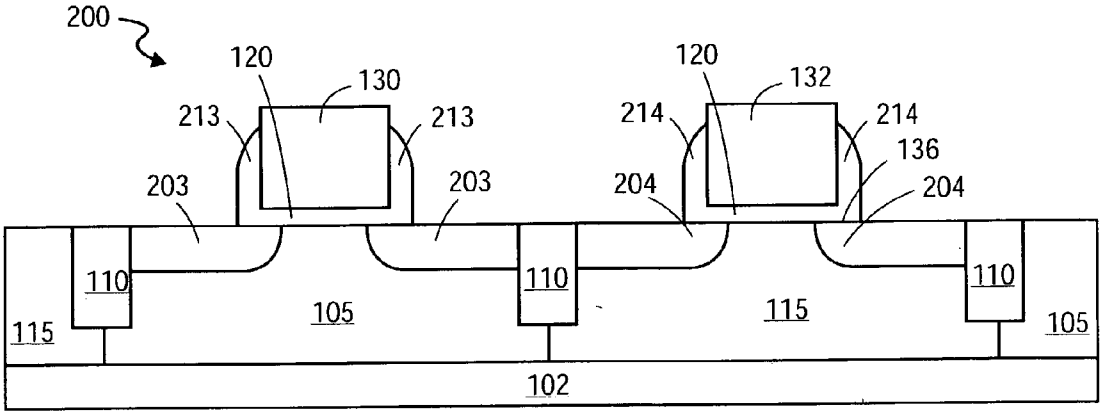
102

FIG. 1


200
120
130
213
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102

FIG. 2

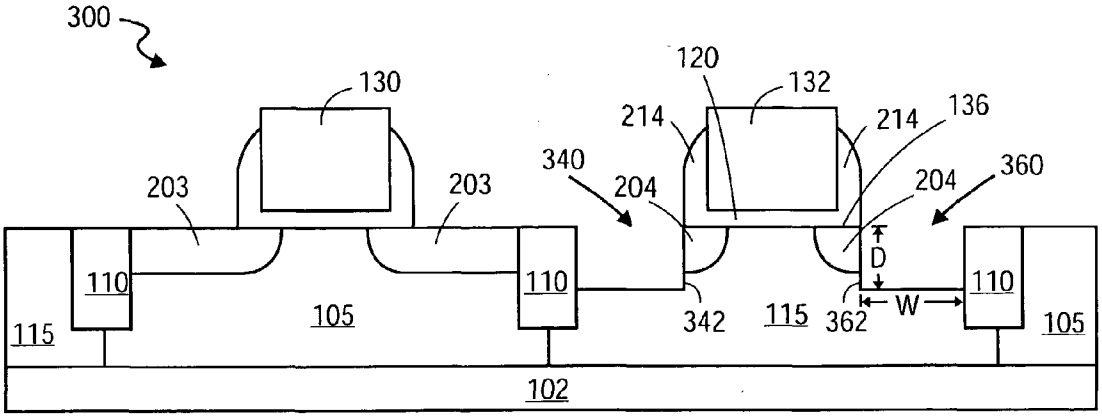


FIG. 3

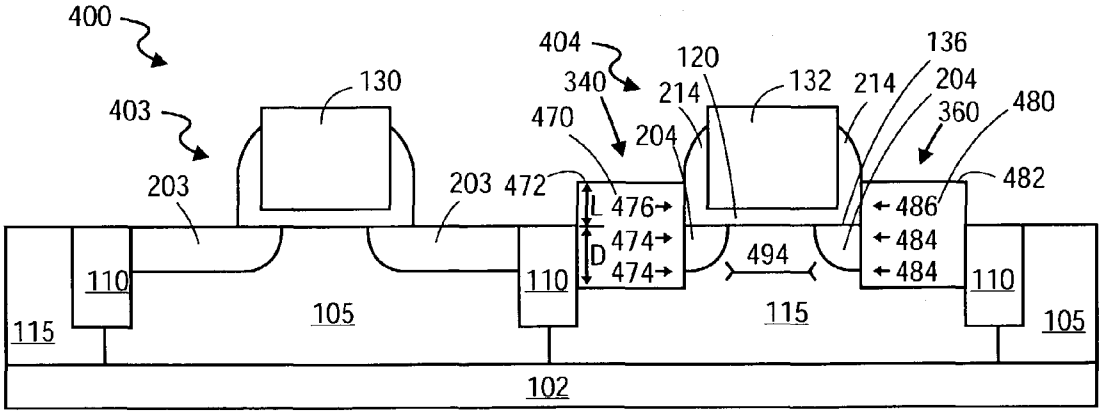


FIG. 4

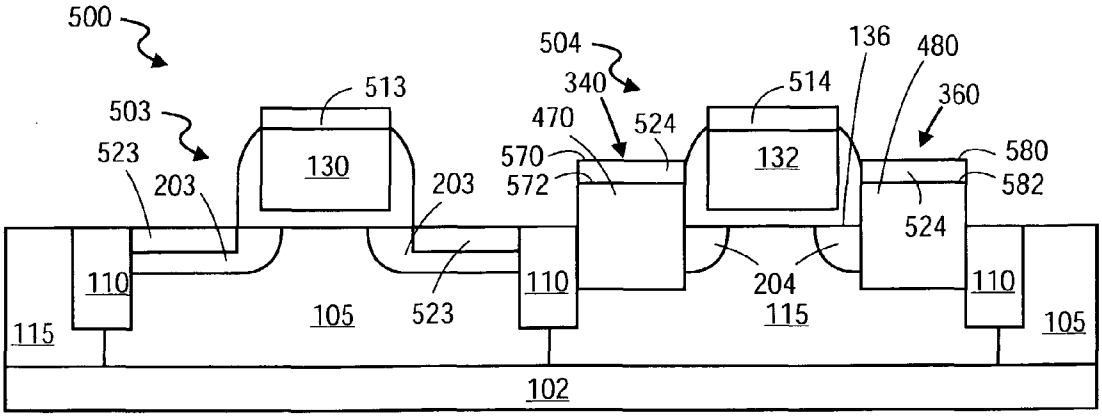
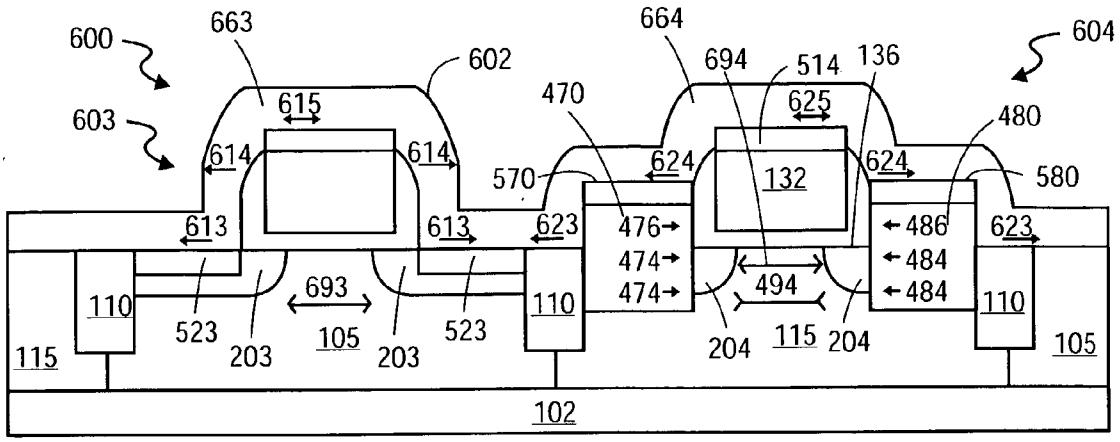


FIG. 5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470
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613
623
476
474
474
486
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484
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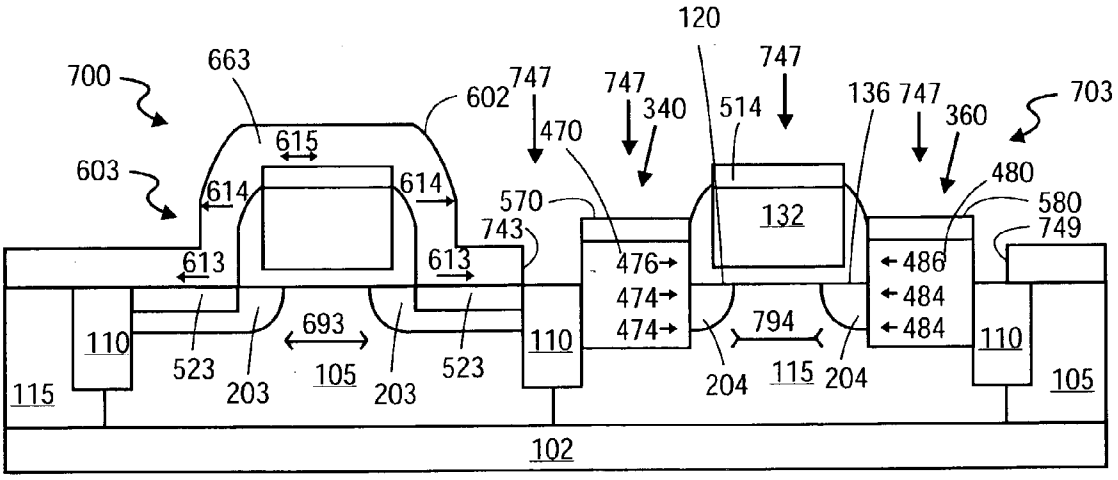
102

FIG. 6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360
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132
580
743
749
613
613
476
474
474
486
484
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110
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523
105
523
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204
105
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203
203
102

FIG. 7

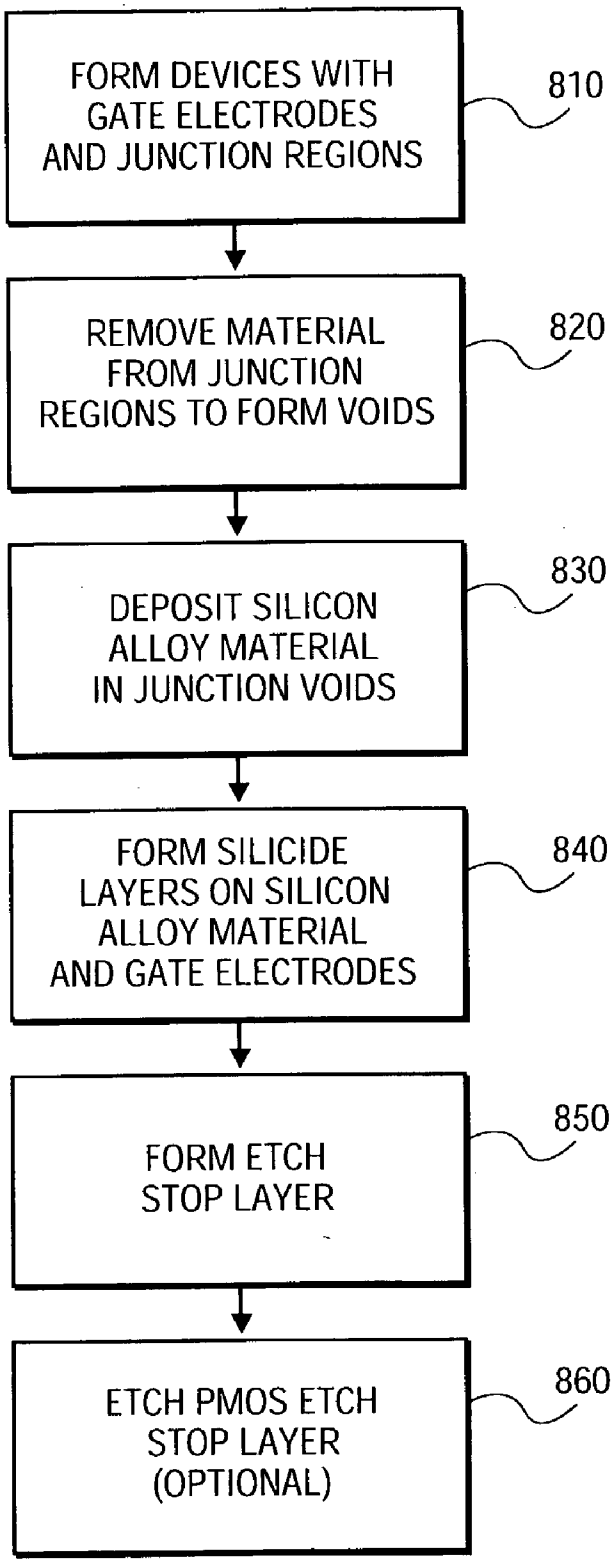
FORM DEVICES WITH GATE ELECTRODES AND JUNCTION REGIONS
810
REMOVE MATERIAL FROM JUNCTION REGIONS TO FORM VOIDS
820
DEPOSIT SILICON ALLOY MATERIAL IN JUNCTION VOIDS
830
FORM SILICIDE LAYERS ON SILICON ALLOY MATERIAL AND GATE ELECTRODES
840
FORM ETCH STOP LAYER
850
ETCH PMOS ETCH STOP LAYER (OPTIONAL)
860

FIG. 8

PMOS TRANSISTOR STRAIN OPTIMIZATION WITH RAISED JUNCTION REGIONS

FIELD

[0001] Circuit devices and the manufacture and structure of circuit devices.

BACKGROUND

[0002] Increased performance of circuit devices on a substrate (e.g., integrated circuit (IC) transistors, resistors, capacitors, etc. on a semiconductor (e.g., silicon) substrate) is usually a major factor considered during design, manufacture, and operation of those devices. For example, during design and manufacture or forming of, metal oxide semiconductor (MOS) transistor semiconductor devices, such as those used in a complementary metal oxide semiconductor (CMOS), it is often desired to increase movement of electrons in N-type MOS device (NMOS) channels and to increase movement of positive charged holes in P-type MOS device (PMOS) channels.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] Various features, aspects, and advantages will become more thoroughly apparent from the following detailed description, appended claims, and accompanying drawings in which:

[0004] **FIG. 1** is a schematic cross-section view of a portion of a semiconductor substrate after forming a well, gate dielectric, and gate electrode of NMOS and PMOS devices.

[0005] **FIG. 2** shows the semiconductor substrate of **FIG. 1** after forming sidewall spacers and junction regions of the NMOS and PMOS devices.

[0006] **FIG. 3** shows the semiconductor substrate of **FIG. 1** after forming of PMOS junction region voids.

[0007] **FIG. 4** shows the semiconductor substrate of **FIG. 1** after depositing of silicon alloy material into the PMOS junction region voids.

[0008] **FIG. 5** shows the substrate of **FIG. 1** after forming of silicide layers on the diffusion regions and gate electrodes of the NMOS and PMOS devices.

[0009] **FIG. 6** shows the substrate of **FIG. 1** after the forming of a conformal etch stop layer over the NMOS and PMOS devices.

[0010] **FIG. 7** shows the substrate of **FIG. 1** after removing an etch stop layer from the PMOS device.

[0011] **FIG. 8** is a flow diagram of a process for forming a CMOS structure having a PMOS device with silicon alloy material deposited in the junction regions such that the silicon alloy material is in a non-planar relationship with the surface of the substrate.

DETAILED DESCRIPTION

[0012] **FIG. 1** is a schematic cross-section view of a portion of a semiconductor substrate after forming a well, gate dielectric, and gate electrode of an NMOS device and a PMOS device. Apparatus **100** (e.g., such as one or more CMOS structures) includes semiconductor substrate **102**, such as a silicon substrate, or epitaxial layer of a semiconductor substrate, having active areas or cell regions defined by isolation areas such as shallow trench isolation structures **110** formed in substrate or epitaxial layer **102**. For example, substrate **102** may be formed or grown from single crystal silicon, and shallow trench isolation (STI) structures **110** may be formed by defining regions (through trench etching) and growing or depositing silicon dioxide (SiO_2) dielectric in the trench openings (e.g., such as formed to height H as shown in **FIG. 1**). In embodiments, STI structures **110** define active areas or cell regions for individual transistor devices (e.g., such as NMOS and PMOS devices of a CMOS structure).

[0013] **FIG. 1** also shows P-type well **105** and N-type well **115** formed in the individual active area or cell region defined by STI structures **110**. For example, P-type well **105** is formed in one region of substrate **102** while N-type well **115** is formed in a second region of substrate **102**. P-type well **105** is formed, such as, by introducing a dopant, such as boron (B) and/or aluminum (Al), into an area of substrate **102** designated for an N-type device. N-type well **115** is formed, such as, by introducing a dopant, such as arsenic (As), phosphorous (P), and/or antimony (Sb) in an area of substrate **102** designated for a P-type device. P-type well **105** and N-type well **115** may have work functions corresponding to the work function of an NMOS device and PMOS device, respectively, of a CMOS circuit. Practices for forming, sizes, and thicknesses (e.g., depths) of STI structures **110** and wells **105** and **115** are known in the art and are, therefore, not presented further herein.

[0014] **FIG. 1** shows substrate **102** after the forming a gate dielectric layer and gate electrode layer over the surface **136** of substrate **102**, and subsequent patterning or removal of unwanted portions of the gate dielectric layer and/or gate electrode layer. For instance, as shown, gate dielectric **120** may be grown or deposited. An example of gate dielectric material that is typically grown by thermal techniques over substrate **102** is SiO_2. It is to be appreciated that, in addition to SiO_2, other gate dielectrics, such as carbon doped oxide (CDO), cubic boron nitride (CBN), phosphosilicate glass (PSG), silicon nitride (Si_3N_4), fluorinated silicate glass (FSG), silicon carbide (SiC) may be used to further optimize the CMOS transistor devices. For example, gate dielectric materials having a high dielectric constant may be used, if desired, for example, to increase the capacitance of the gate. Practices of forming, sizes, and thicknesses (e.g., heights) of gate dielectric **120** are known in the art, and are, therefore, not described further herein.

[0015] **FIG. 1** shows a structure which includes gate electrodes **130** and **132** over the surface of substrate **102**, such as by deposition onto gate dielectric **120**. NMOS gate electrode **130** and PMOS gate electrode **132** may each be deposited to a thickness of, for example, 150-2000 angstroms (e.g., 15-200 nanometers (nm)). Accordingly, the thickness of NMOS gate electrode **130** and PMOS gate electrode **132** are each scalable and may be selected or chosen based on integration issues related to device performance. NMOS gate electrode **130** has a work function corresponding to the work function of an N-type device. PMOS gate electrode **132** has a work function corresponding to the work function of a P-type device. In embodiments, NMOS gate electrode **130** and PMOS gate electrode **132** are each silicon deposited by chemical vapor deposition (CVD) and then doped to form N-type and P-type materials, respec-

tively, such as the doping is described above with respect to forming the N-type and P-type material of N-type well **115** and P-type well **105**, respectively. For instance, NMOS gate electrode **130** may be doped at the same time that the corresponding NMOS junction regions are doped (e.g., such as NMOS junction regions **203**, shown in **FIG. 2**), and PMOS gate electrode **132** may be doped at the same time the PMOS junction regions are doped (e.g., such as PMOS junction regions **204**, shown in **FIG. 2**). Practices for forming, sizes (e.g., area of gate dielectric **120** the gate electrodes cover) and additional thicknesses (e.g., heights) of NMOS gate electrode **130** and PMOS gate electrode **132** are known in the art, and are, therefore, not presented further herein.

[**0016**] **FIG. 1** further shows the substrate after removal of undesired portions of gate dielectric **120** and NMOS gate electrode **130** and PMOS gate electrode **132**, such as by patterning a mask layer over a defined area for NMOS gate electrode **130** and PMOS gate electrode **132** and etching away the undesired exposed portions not covered by the mask. For example, undesired portions of gate dielectric **120** and one or more types of gate electrode material may be patterned to form gate dielectric **120** and NMOS gate electrode **130** over NMOS device **103**, and to form gate dielectric **120** and PMOS electrode **132** over PMOS device **104**, such as by patterning using conventional techniques, such as plasma etchant, sputter etchant, and/or a chlorine-based etch chemistry. Masking and/or removal of gate dielectric and gate electrodes in the NMOS and PMOS devices may be performed simultaneously or in separate patterning, masking, and/or etching operations as are well known in the art, and are, therefore, not further described herein. For instance, according to embodiments, NMOS gate electrode **130** and PMOS gate electrode **132** are polysilicon deposited by CVD and then masked and etched.

[**0017**] **FIG. 2** shows the semiconductor substrate of **FIG. 1** after forming sidewall spacers and junction regions of the NMOS and PMOS devices. **FIG. 2** shows NMOS gate isolation spacers **213** and PMOS gate isolation spacers **214** that may be formed, of a suitable dielectric incorporated around NMOS gate electrode **130** and PMOS gate electrode **132**, respectively, to insolate the individual electrodes of the transistor devices. For example, NMOS gate isolation spacers **213** may be formed by depositing dielectric material, similar to dielectric materials described above for gate dielectric **120**, along sidewalls of gate dielectric **120** and NMOS gate electrode **130** structure shown in **FIG. 1** and then patterning and etching the formed or deposited dielectric material to create NMOS gate isolation spacers **213**, such as patterning and etching techniques described above for NMOS and PMOS gate electrodes **120** and **130**. Similarly, PMOS gate isolation spacers **214** may be formed of a suitable dielectric material incorporated around PMOS gate electrode **132** to insulate the individual electrodes of the transistor devices. For example, PMOS gate isolation spacers **214** may be formed of a similar material and using a similar method to that described above for forming NMOS gate isolation spacers **213**. It is contemplated that NMOS gate isolation spacers **213** may be the same or a different material than PMOS gate isolation spacers **214**. In an embodiment NMOS gate isolation spacers **213** and PMOS gate isolation spacers **214** are SiO_2. Moreover, processes for forming shapes, sizes, and thicknesses of gate isolation spacers such as NMOS gate isolation spacers **213** and PMOS gate isolation spacers **214** are known in the art (e.g., and are sometimes referred to as "sidewall spacers" or "shoulder spacers"), and, therefore, are not further presented herein.

[**0018**] **FIG. 2** shows NMOS junction regions **203** and PMOS junction regions **204** (e.g., also referred to as "source-drain regions" or "diffusion regions") that may be formed by a junction implant (e.g., such as implanting with arsenic, phosphorous, and/or antimony for N-type junction regions **203** and boron and/or aluminum for P-type junction regions **204**) and possibly include additionally corresponding type tip implants. Thus, NMOS junction regions **203** may be formed, such as by doping portions of P-type well **105** to form those junction regions. For example, NMOS junction regions **203** may be formed, in accordance with the characteristics of an NMOS device, such as by doping the material of P-type well **105**, to form the N-type material in NMOS junction regions **203**, as described above with respect to doping to form the N-type material of N-type well **115**. Moreover, PMOS junction regions **204** may be formed, such as by doping portions of N-type well **115** to form those junction regions. For example, portions of N-type well **115** may be doped to form the P-type material in PMOS junction regions **204**, in accordance with the characteristics of a PMOS device, such as by doping as described with respect to doping to form the P-type material of P-type well **105**.

[**0019**] In addition, as noted above, according to embodiments, corresponding tip implants may be included in or incorporated with the junction regions. For example, NMOS junction regions **203** may also include additional N-type doping, such as implanting arsenic, phosphorous, and/or antimony into NMOS junction regions **203** adjacent to NMOS gate electrode **130** at an angle directed at the channel. Also, for example, PMOS junction regions **204** may also include additional P-type angled doping, such as implanting boron and/aluminum into PMOS junction regions **204** adjacent to PMOS gate electrode **132**.

[**0020**] More specifically, embodiments include forming NMOS junction regions **203** by doping P-type well **105** with phosphorous, and further subsequently doping the region of P-type well **105** adjacent NMOS electrode **130** further with phosphorous to form tip implants. Also, embodiments include forming PMOS junction regions **205** by doping N-type well **115** with boron, and further subsequently doping portions of N-type well **115** adjacent to PMOS gate electrode **132** with boron to form P-type tip implants.

[**0021**] Portions of P-type well **105** may be doped with tip implants to form N-type material before or after formation of NMOS spacers **213**, such as by doping as described above with respect to doping to form the N-type material of N-type well **115**. Similarly, **FIG. 2** shows PMOS tip implants **204** that may be formed, such as by doping portions of N-type well **115** to form those tip implants. For example, portions of N-type well **115** may be lightly doped to form P-type material before or after formation of PMOS spacers **214**, such as by doping as described above with respect to doping to form the P-type material of P-type well **105**. According to embodiments, formation of NMOS gate isolation spacers **213**, PMOS gate isolation spacers **214**, NMOS junction regions **203**, and/or PMOS junction regions **204** may occur in any order as appropriate, such as in accordance with the characteristics of the desired device. Practices for forming,

sizes, and thicknesses (e.g., depths) of NMOS junction regions **203** and PMOS junction regions **204**, and possibly additionally including corresponding tip implants, are known in the art and are, therefore, not presented further herein.

[**0022**] **FIG. 3** shows the semiconductor substrate of **FIG. 1** after the forming of PMOS junction region voids. **FIG. 3** shows first PMOS junction region void **340** and second PMOS junction region void **360** that may be formed, by removing a portion of or all of PMOS junction regions **204**, and/or portions of N-type well **115** (e.g., such as portions of N-type well **115** adjacent to PMOS gate electrode **132**). According to embodiments, first void **340** and second void **360** may be formed at various surface areas of surface **136** and to various dimensions (e.g., such as to depth D, and width W, as shown in **FIG. 3**, and extending an extent E, not shown, but perpendicular to the cross-sectional view of **FIG. 3**) in N-type well **115** within the space between STI **110** and an effective width of a channel under PMOS gate electrode **132** for the device. For example, in embodiments, first void **340** and second void **360** may be formed to a depth D in the range between 50 nanometers and 200 nanometers below surface **136**, and to a width W in the range of between 90 nanometers and 270 nanometers. It is to be appreciated that, in embodiments, width W may be scaled according to the gate length, such as to be between one and three times the gate length. In addition, according to embodiments, first void **340** and second void **360** may be formed to a depth in the range of between 20 nanometers and 250 nanometers below surface **136**, so that deposition of a silicon alloy in first void **340** and second void **360** to a height that is non-planar with surface **136** (e.g., such as a height extending above surface **136**) provides a PMOS device that operates sufficiently and in accordance with characteristics of the desired PMOS and/or CMOS structure (e.g., such as a desired PMOS as shown by the device on the right side of **FIG. 6** or **7**, or desired CMOS, such as shown by structures **600** or **700**).

[**0023**] For example, first PMOS junction region void **340** and second PMOS junction region void **360** may be formed simultaneously or independently by patterning, etching, and/or recess etching (e.g., such as is described above for removing undesired portions of electrodes **130** and **132**) to various desired sizes and depths characteristic for NMOS and PMOS devices by operations as are known in the art, and are therefore not described further herein. In addition, embodiments include wherein a surface of the substrate proximate to the first junction region (e.g., such as first PMOS junction region void **340**) defines a first substrate sidewall surface **342**, and a surface of the substrate proximate to the second junction region (e.g., such as second PMOS junction region void **360**) defines a second substrate sidewall surface **362**.

[**0024**] **FIG. 4** shows the semiconductor substrate of **FIG. 1** after depositing of silicon alloy material into the PMOS junction region voids (e.g., such as first PMOS junction region void **340** and second PMOS junction region void **360**). **FIG. 4** shows silicon alloy material **470** disposed in first PMOS junction region void **340** and silicon alloy material **480** disposed in second PMOS junction region void **360** such that surface **472** of the resulting first junction region is in a non-planar relationship with surface **136** of the substrate, and such that surface **482** of the resulting second junction region is also in a non-planar relationship with surface **136** of the substrate. Silicon alloy materials **470** and **480** may be formed of a suitable silicon alloy material disposed in first and second PMOS junction region voids **340** and **360**, respectively, to cause strain **494** during performance of the device in a region of N-type well material **115** between silicon alloy material **470** and silicon alloy material **480** (e.g., such as a strain in a region that may be referred to as the PMOS channel). Suitable silicon alloy materials that may be used to cause strain **494** include one or more of the following: silicon germanium (SiGe), silicon carbide (SiC), nickel silicide (NiSi), titanium silicide ($TiSi_2$), cobalt silicide ($CoSi_2$), and possibly may be doped with one or more of boron and/or aluminum. For example, silicon alloy material **470** and **480** may include a material having a silicon alloy lattice spacing that is different than the lattice spacing of the substrate material of N-type well **115**. More specifically, in operation of the PMOS device, silicon alloy materials **470** and **480** may cause a compression in the well material or a compressive strain at strain **494** in a region of N-type well **115** caused by silicon alloy **470** and **480** having a lattice spacing that is a larger lattice spacing than the lattice spacing of N-type well **115** in that region.

[**0025**] Moreover, according to embodiments, silicon alloy materials **470** and **480** have a surface of the first junction region **472** and a surface of the second junction region **482** that are superior to the top surface (e.g., surface **136**) of the substrate as viewed. The non-planar relationship between the junction regions and the substrate surface tends to cause first silicon alloy strain from point **474** below substrate surface, as well as first silicon alloy strain above substrate surface **476**, and second silicon alloy strain below the substrate surface **484** and second silicon alloy strain above the substrate surface **486** which any and/or all of contribute to operation strain **494**. For example, the thickness of silicon alloy material **470** and/or **480** deposited (e.g., the length L plus the depth D forming the height to surfaces **472** and/or **482**) can be controlled by the time duration of the deposition and/or the deposition concentration, or deposition rate of the deposition operation. In addition, in embodiments, the silicon alloy material disposed or deposited in the first junction region (e.g., such as silicon alloy material **470**) may be attached super adjacent to first substrate sidewall surface **342** and the silicon alloy material disposed or deposited in the second junction region (e.g., such as silicon alloy material **480**) may be attached super adjacent to second substrate sidewall surface **362**.

[**0026**] Thus, according to embodiments, first void **340** and second void **360** may be formed at suitable surface areas of surface **136** and to various dimensions and depths within N-type well **115** sufficient to provide desired operational strains **474**, **476**, **484**, **486**, and/or **494**; including strains desired in accordance with characteristics of a desired PMOS device and/or CMOS structure (e.g., such as desired PMOS device, as shown by the device on the right side of **FIG. 6** or **7**, or desired CMOS structure, such as shown by structures **600** or **700**). Hence, the dimensions and depth of first void **340** and second void **360**, silicon alloy materials **470** and **480**, and non-planar relationship of surfaces **472** and **482** with respect to surface **136** may be selected to cause a compressive strain at strain **494** in a range between 0.1 percent and 10 percent. Particularly, a proper design may be chosen to provide a compressive strain at strain **494** in the range between 0 percent and 2 percent or 0.5 percent and 2.5

percent (e.g., for example, a compressive strain of approximately 1 percent). It is to be appreciated that, in embodiments, a sufficient compressive strain at strain **494** may be accomplished according to embodiments having a non planar relationship where length L is in a range between a fraction of an Angstrom and 200 nanometers.

[**0027**] According to embodiments, silicon alloy material **470** and/or **480** may be formed or deposited into first PMOS junction region void **340** and/or second PMOS junction region void **360**, respectively, such by selective deposition, CVD deposition, or epitaxial deposition. For example, an epitaxial layer of single crystal semiconductor film may be formed upon a single crystal substrate, where the epitaxial layer has the same crystallographic characteristics as the substrate material, but differs in type or concentration of dopant. More particularly, silicon alloy materials **470** and/or **480** may be formed by selective CVD deposition, and possibly include epitaxial deposition of single crystal silicon alloy with the same crystal structure as that of the material of N-type well **115** (e.g., having the same crystal structure meaning that if the material of N-type well **115** has a crystal grade of, for example, **100**, **110**, etc., then the silicon alloy deposited will have a similar or the same grade crystal grade, such as, **100**, **110**, etc.).

[**0028**] Furthermore, according to embodiments, silicon alloy materials **470** and/or **480** may be formed by epitaxial deposition of boron doped silicon germanium (SiGe), then annealing to remove the boron from the silicon germanium. Therefore, a layer of $Si_{1-x}Ge_x$ may be grown on top of a substrate of Si such that the silicon germanium has a bulk relaxed lattice constant that is larger (e.g., such as by **4.2** percent) than the silicon it is grown on. The resulting misfit dislocation or dislocations at the block or blocks where the silicon germanium bonds to the silicon may create strains **474**, **476**, **484**, **486**, and/or **494**. In other words, strain **494**, such as a compressive strain, may result from the germanium atoms squeezed into the silicon of silicon alloy materials **470** and **480** such that those silicon alloys have a lattice spacing different and distorted as compared to the silicon material of N-type well **115**.

[**0029**] Suitable processes for forming or growing of silicon alloy materials **470** and/or **480** include by vapor phase (VPE), liquid phase (LPE), or solid phase (SPE) blocks of silicon processing. For example, one such CVD process that is applicable to VPE of silicon includes: (1) transporting reactants to the substrate surface; (2) reactants absorbed on the substrate surface; (3) chemical reaction on the surface leading to formation of a film and reaction products; (4) reaction products deabsorbed from the surface; and (5) transportation away of the reaction product from the surface.

[**0030**] In addition, suitable forming of silicon alloy comprises selective epitaxial deposition, formation, or growth known in the art as Type **1** selective epitaxial deposition. Using Type **1** deposition, silicon alloy deposition would be occurring only on bare silicon substrates within the openings of the oxide film, and minimal, if any, growth on the oxide. Thus, in the embodiment shown in **FIG. 4**, for example, silicon alloy material **470** and/or **480** are formed on surfaces of voids **340** and/or **360** respectively (e.g., including PMOS junction regions **204**), but are not formed on surfaces of STI **110**, gate dielectric **120**, PMOS gate isolation spacers **214**, or PMOS gate electrode **132**. Moreover, it is to be appreciated, that in embodiments, silicon alloy material (e.g., such as material **470** and/or **480**) may be formed on surfaces of voids **340** and/or **360**, respectively, as well as on gate surfaces of STI **110**, gate dielectric **120**, PMOS gate isolation spacers **214** and/or PMOS gate electrode **132**. Specifically, embodiments include silicon alloy material **470** and/or **480** formed by Type **1** selective epitaxial deposition using a silicon source including one or more of the following: silicon germanium (SiGe), silicon carbide (SiC), nickel silicide (NiSi), titanium silicide ($TiSi_2$), cobalt silicide ($CoSi_2$), halides, $SiCl_4$, $SiHCl_3$, $SiHBr_3$, and $SiBr_4$ at suitable temperatures. Also, SiH_2Cl_2, SiH_4 may be used as a silicon source if hydrogen chloride (HCl), chlorine (Cl_2) is present.

[**0031**] Suitable selective epitaxial formation also includes Type **2** selective epitaxial deposition where selectivity of deposition is non-critical. Using Type **2** deposition, formation or growth of the silicon alloy occurs on bare silicon substrate, as well as on the oxide film, and thus when this type of deposition is made, an interface between the epitaxial layer of silicon alloy formed on the bare silicon substrate and a polysilicon layer of silicon alloy formed on the oxide film is created. The angle of this interface relative to the film growth direction depends on the crystallographic orientation of the substrate. Thus, in the embodiment shown in **FIG. 4**, for example, silicon alloy material **470** and/or **480** are formed on surfaces of voids **340** and/or **360**, respectively (e.g., including PMOS junction regions **204**), and may also be formed on surfaces of STI **110**, gate dielectric **120**, PMOS gate isolation spacers **214**, and/or PMOS gate electrode **132**. Particularly, embodiments include Type **2** selective epitaxial deposition using SiH_4, SiGe, SiC, NiSi, $TiSi_2$, and/or $CoSi_2$ as the silicon source.

[**0032**] Consequently, according to embodiments, subsequent to formation, undesired portions of silicon alloy material **470** and/or **480** may be patterned and/or etched away using various techniques known in the art (e.g., such as is described above for removing undesired portions of electrodes **130** and **132**) and, therefore, not presented herein.

[**0033**] Thus, according to embodiments, silicon alloy material **470** and/or **480** may be formed having surface of the first junction region **472** and/or surface of the second junction region **482** superior to a top surface of the substrate (e.g., such as surface **136**) by a length in the range between 5 nanometers and 150 nanometers in length. For example, as shown in **FIG. 4**, surface of the first junction region **472** and/or surface of the second junction region **482** may extend superior to surface **136** of the substrate by length L between 400 and 500 angstroms (e.g., 40-50 nanometers), and silicon alloy materials **470** and/or **480** may extend into N-type well **115** to a depth D, as shown in **FIG. 4**, in a range of between 20 and 250 nanometers in depth. Moreover, contemplated are embodiments where depth D is approximately 120 nanometers and length L is in the range between 40 and 50 nanometers in length.

[**0034**] Furthermore, in embodiments, silicon alloy materials **470** and/or **480** may be deposited, as described above, and then doped to form junction regions in accordance with the characteristics of a desired PMOS device. For example, after deposition of silicon alloy materials **470** and/or **480**, one or both of those materials may be doped such as by doping those materials, as described above with respect to

doping to form the P-type material of P-type well **105**. Thus, for example, silicon alloy materials **470** and/or **480** may be formed as, or may be doped to be, or to increase their polarity as electrically positively charged (P-type) junction region material. Consequently, it is contemplated that silicon alloy material **470** may be the same or different material, and may be doped the same or differently than silicon alloy material **480**. Hence, according to embodiments, silicon alloy materials **470** and **480** may include silicon germanium formed by selective CVD deposition of an epitaxial layer having depth D of **120** nanometers and length L of **50** nanometers above surface **136** and subsequently doped with boron after deposition.

[**0035**] As a result, silicon alloy materials **470** and/or **480** may be selected to be materials of a type, doped suitably, in a junction region void of suitable dimensions, and/or extending to a length L above surface **136** sufficient to operate and/or provide desired strains **474**, **476**,**484**, **486**, and/or **494** in accordance with characteristics of a desired PMOS and/or CMOS structure (e.g., such as desired PMOS, as shown by the device on the right side of **FIG. 6** or **7**, or desired CMOS, such as shown by structure **600** or **700**).

[**0036**] In addition, according to embodiments, length L to surface of the first junction region **472** and/or a length to surface of the second junction region **482** may include a silicide layer and/or may be complemented by an additional length superior to surface **136** (as viewed) and including a layer of silicide material. For instance, **FIG. 5** shows the substrate of **FIG. 1** after forming silicide layers on the diffusion regions and gate electrodes of the NMOS and PMOS devices. NMOS junction silicide layers **523**, NMOS gate silicide layer **513**, PMOS junction region silicide layers **524**, and PMOS gate silicide layer **514** formed in, on or in and on, NMOS junction regions **203**, NMOS gate electrode **130**, PMOS junction regions (e.g., such as portions or all of silicon alloy material **470** and **480**, and non or some of PMOS junction regions **204**) and PMOS gate electrode **132** respectively. Silicide layers **523**, **513**, **524**, and/or **514** may be formed of the same or various suitable silicide materials and/or by the same or various suitable operations to provide an appropriate surface for coupling to an electrical contact formed to them in accordance with characteristics for the desired PMOS device and/or CMOS structure. For example, one or more of silicide layers **523**, **513**, **524**, and **514** may be formed by sputtering down a blanket of suitable silicide material (e.g., such as nickel (Ni), titanium (Ti), cobalt (Co), and annealing the silicide material so that it reacts with any exposed silicon to form the appropriate silicide layer (e.g., such as nickel silicide (NiSi), titanium silicide ($TiSi_2$), and/or cobalt silicide ($CoSi_2$)). After sputtering down the blanket of suitable silicide material, undesired portions can be etched away (e.g., such as is described above for removing undesired portions of electrodes **130**), such as by removal of any unreacted silicide material (e.g., such as any unreacted nickel, titanium, and/or cobalt).

[**0037**] According to embodiments, a layer of silicide material may be deposited along the entire exposed surface of structure **500** (e.g., such as NMOS device **503** and PMOS device **504** of a CMOS structure) and heated so that the silicide material partially diffuses into selected portions of that entire surface. Thus, it is contemplated that layer of silicide material **523**, **513**, **524**, and/or **514** may consume a portion of NMOS junction regions **203**, NMOS gate electrode **513**, silicon alloy materials **570** and **580**, and/or PMOS gate electrode **514**, respectively. More particularly, layers of silicide material **523**, **513**, **524**, and **514** may comprise nickel silicide consuming approximately **20** nanometers of silicon alloy materials **470** and **480** beginning at surfaces **472** and **482** and extending downward, as shown in **FIG. 5**. However, the formation of silicide layers **524** and **514** should be such that the formation of those silicide layers or subsequent operations do not cause silicide **524** and **514** to short together (e.g., such as by effecting the length L or surface height **570**, **580**, and/or height of silicide **514** to be effected such that silicides **524** short to silicide **514**). Practices for forming, sizes, and thicknesses (e.g., depth and height) of suitable silicide layers are well known in the art and are, therefore, not further described herein.

[**0038**] **FIG. 6** shows the substrate of **FIG. 1** after forming a conformal etch stop layer over the NMOS and PMOS devices. **FIG. 6** shows NMOS conformal etch stop layer **663** covering exposed surfaces of NMOS device **603** and PMOS conformal etch stop layer **664** covering exposed surfaces of PMOS device **604**. NMOS etch stop layer **663** and/or PMOS etch stop layer **664** may be formed by the same or various suitable operations known in the art and/or of the same or various suitable materials, such as by deposition, sputter deposition, and/or growth of silicon nitride (Si_3N_4) SiO_2, PSG, SiC, as well as various other appropriate materials, sizes, and thicknesses suitable for and in operations suitable for depositing those materials such that surfaces below NMOS etch stop layer **663** and/or PMOS etch stop layer **664** are protected (e.g., such as silicide layers therebelow).

[**0039**] Further, according to embodiments, NMOS etch stop layer **663** and/or PMOS etch stop layer **664** may include a material that causes NMOS tension **693** in a region of P-type well material **105**, as a result of tensile attributes of NMOS etch stop layer such as shown by NMOS etch stop layer tensile vectors **613**, **614**, and **615**. Alternatively, an etch stop material may be selected, that causes PMOS tension **694** in a region of N-type well **115** such as a tension resulting from PMOS etch stop tensile vectors **623**, **624**, and **625**. However, while the region of P-type well material may result in a channel that is overall in tension, as a result of the effect of tensile vectors **613**, **614**, and **615** of NMOS etch stop layer **663**, the region of N-type well material **115** may experience a channel that overall is in compression of the tensile strain **694** that may be the result of vectors **623**, **624**, and **625** of PMOS etch stop layer **664** are counteracted by compressive strain **494** resulting from compressive vectors **474**, **476**, **484**, and **486**. Moreover, as first surface height **570** and second surface height **580** extend above surface **136**, PMOS etch stop layer tensile vectors **623** and **624** have less of an effect and create a less powerful PMOS tension **694** than that of NMOS tension **693**, because vectors **623** and **624** are pushed farther away from the region of N-type well material **115** (e.g., the PMOS channel) by the formed or disposed silicon alloy materials **470** and **480** whose surfaces **570** and **580** extend above surface **136**. Practices for forming, sizes, and thicknesses of etch stop layer **663** and/or **664** are known in the art and, are therefore not presented further herein.

[**0040**] **FIG. 7** shows the substrate of **FIG. 1** after removing an etch stop layer from the PMOS device. **FIG. 7** shows an embodiment where PMOS etch stop layer **664** has been removed from one or more portions of the surfaces of PMOS

device **703** (e.g., such as is described above for removing undesired portions of electrodes **130** and **132**). Thus, PMOS etch stop layer **664** may be removed, such as by patterned etching, selective etching, or other suitable removal techniques from PMOS surfaces **747** which may include the surfaces of one or more of STI **110**, surface **170**, surface **180**, surfaces of gate isolation spacers for PMOS gate electrode **132**, and/or the surface of PMOS gate electrode silicide **514**. Moreover, removal of PMOS etch stop layer **664** may adjacent to a proximate end of STI **110**, along the surface of STI **110** (e.g., such as shown by edge **749**), or adjacent to a distal end of STI **110** (e.g., such as shown by edge **743**). Practices of removing, area sizes removed, and thicknesses removed of etch stop layer **664** are known in the art and, are therefore not presented further herein.

[**0041**] According to embodiments, a sufficient or selected portion of area of, a thickness of the layer, and/or all of PMOS etch stop layer **664** is removed to decrease or eliminate any tension or tensile stress resulting from PMOS etch stop layer **664** where it has been removed. Thus, the residual strain **794** in N-type well **115** will include more of a compression in the channel as the strain associated with vectors **474**, **476**, **484**, and **486** are kept largely in tact, while those of vectors **623**, **624**, and **625** have been substantially removed.

[**0042**] Furthermore, embodiments include formation of a dielectric layer (e.g., such as a planarized interlayer dielectric (ILD) formed of SiO_2, PSG, Si_3N_4, and/or SiC, as well as various other appropriate materials for the CMOS structure desired) formed over any of the structures shown in **FIGS. 4-7**. Practices for forming, sizes, and thicknesses of a dielectric layer formed over any of the structures shown in **FIGS. 4-7** is known in the art and is, therefore, not presented further herein.

[**0043**] **FIG. 8** is a flow diagram of a process for forming a CMOS structure having a PMOS device with silicon alloy material deposited in the junction regions such that the silicon alloy material is in a non-planar relationship with the surface of the substrate. At **810**, NMOS and PMOS devices of a CMOS structure are formed on a substrate having the appropriate wells, junction regions, gate dielectrics, gate electrodes, and gate isolation spacers, and STIs (e.g., such as is shown in **FIG. 2**). At **820**, a portion of PMOS junction regions **204** and possibly N-type well **115** are removed to a width and depth as desired adjacent PMOS gate electrode **132** (e.g., such as is shown in **FIG. 3**). For example, first and second PMOS junction region voids **340** and **360** may be formed such as by etching, as described herein.

[**0044**] At **830**, silicon alloy material is deposited or formed in the PMOS junction regions such that a surface of the first junction region and a surface of the second junction region are in a non-planar relationship with the surface of the substrate (e.g., for example, as shown in **FIG. 4**). For example, silicon germanium, doped silicon germanium, silicon carbide, silicon carbon, carbon doped silicon with lattice spacings different from than the silicon substrate (e.g., N-type well **115**) can be deposited including by an operation using one or more of CVD, epitaxial deposition, and/or selective deposition. Thus, for a PMOS device, such as shown by **404**, a silicon alloy having a lattice spacing larger than that of the substrate can be deposited to provide a compressive strain in the substrate (e.g., such as in the PMOS channel).

[**0045**] On the other hand, for an NMOS device, embodiments include formation of structure **404** where the electrical type of the materials is reversed (e.g., such that well **115** is P-type material, gate electrode **132** is N-type material, etc. as necessary in accordance with the characteristics of the desired NMOS device). A silicon alloy material having a lattice spacing that is smaller than the silicon substrate (e.g., such as silicon carbide, silicon carbine, and/or carbon doped silicon) can be deposited into a first and second NMOS junction region void (e.g., the NMOS equivalence of voids **340** and **360**) to cause a tensile or tension in the channel of the NMOS device (e.g., such as by creating the opposite vectors of those shown by **474**, **476**, **484**, **486**, and **494**).

[**0046**] For example, a surface of the substrate may define a top surface of the substrate and the surface of the first junction region, and the surface of the second junction region (e.g., of either a PMOS or NMOS device embodiment, as described above) are superior to the top surface of the substrate. Deposition of the silicon alloy material may include depositing a thickness or amount of the material sufficient to cause a desired strain (e.g., a tension, or compression) in the substrate (e.g., such as in a region of the well or channel of the device), as desired. Moreover, the deposition of silicon alloy material may include a concentration or type of silicon alloy material having a silicon alloy lattice spacing that comprises a different lattice spacing (e.g., smaller or larger) than the lattice spacing of the substrate material, as desired, to cause the target strain in the substrate. Furthermore, the deposition of the silicon alloy material may comprise deposition of one or more of silicon germanium, silicon carbide, doped with one or more of boron, and/or aluminum to form an electrically positive charge junction region material.

[**0047**] At **840**, silicide layers are formed on the silicon alloy material and gate electrode (e.g., such as is shown in **FIG. 5**). For example, nickel, titanium, and/or cobalt may be deposited onto the exposed surfaces, as shown in **FIG. 4**, in a manner as known in the art such that the nickel, titanium, and/or cobalt reacts with any exposed silicon to form a silicide, and then any unreacted portions may be etched away. Thus, the silicide layers may consume of the silicon alloy material and/or gate electrode.

[**0048**] At **860**, an etch stop layer may be formed over the current surfaces of the device (e.g., such as is shown in **FIG. 6**). For example, a conformal layer of tensile silicon nitride can be deposited on the NMOS and PMOS device sufficient to cause a compression in the NMOS channel. Moreover, the type, thickness, and/or method of deposition of the etch stop layer may be selected such that the resulting tension in the PMOS channel does not overcome the compression from the silicon alloy deposition selected.

[**0049**] Correspondingly, according to embodiments, a tensile etch stop layer may be selectively formed only over the NMOS portion of a CMOS structure. Alternately, according to embodiments, a tensile etch stop layer formed over a CMOS structure may be subsequently removed from the PMOS portion of the CMOS structure.

[**0050**] Although **FIGS. 1-8** describe formation of a CMOS structure having an NMOS device and PMOS device therein, embodiments include formation of a PMOS device portion, as described above (e.g., such as device **404**, **504**, **604**, and/or **703**) without the NMOS device. Thus, contem-

plated formation of independent single PMOS devices, single PMOS devices coupled to form a device other than a CMOS structure multiple coupled PMOS devices, or other appropriate circuit devices on a substrate where the description above with respect to silicon alloy material formed or disposed in junction regions such that the surface of the silicon alloy material is in a non-planar relationship with the surface of a substrate applies.

[0051] The invention is described with reference to specific embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set forth in the claims. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.

What is claimed:

1. An apparatus comprising:

a substrate;

a device on the substrate including a gate electrode on a surface of the substrate and a first junction region and a second junction region in the substrate adjacent the gate electrode; and

a silicon alloy material disposed in each of the first junction region and the second junction region such that a surface of the first junction region and a surface of the second junction region are in a non-planar relationship with the surface of the substrate.

2. The apparatus of claim 1, wherein a surface of the substrate defines a top surface of the substrate and the surface of the first junction region and the surface of the second junction region are superior to the top surface of the substrate.

3. The apparatus of claim 1, wherein the surface of the first junction region and the surface of the second junction region are superior to the top surface of the substrate by a length in the range of between 5 nanometers and 150 nanometers.

4. The apparatus of claim 3, wherein the first junction region and the second junction region define a depth in the range of between 30 nanometers and 250 nanometers in depth.

5. The apparatus of claim 1, wherein the substrate is under a strain caused by a silicon alloy lattice spacing of the silicon alloy.

6. The apparatus of claim 1, wherein the silicon alloy material has a silicon alloy lattice spacing that is different than a lattice spacing of the substrate material.

7. The apparatus of claim 6, wherein the substrate is under a compressive strain caused by the silicon alloy lattice spacing being a larger lattice spacing than the lattice spacing of the substrate material.

8. The apparatus of claim 1, wherein a surface of the substrate proximate to the first junction region defines a first substrate sidewall surface and a surface of the substrate proximate to the second junction region defines a second substrate sidewall surface and the silicon alloy material disposed in the first junction region is attached to the first substrate sidewall surface and the silicon alloy material disposed in the second junction region is attached to the second substrate sidewall surface.

9. The apparatus of claim 1, wherein the silicon alloy material comprises an epitaxial layer of silicon alloy material.

10. The apparatus of claim 1, wherein the silicon alloy material comprises one of silicon germanium (Si_{y-x} Ge_x), silicon carbide (Si_{y-x} C_x), nickel silicide (NiSi), titanium silicide ($TiSi_2$), and cobalt silicide ($CoSi_2$).

11. The apparatus of claim 1, further comprising a layer of silicide material on the surface of the first junction region, the surface of the second junction region, and the gate electrode, wherein the layer of silicide material comprises one of nickel silicide (NiSi), titanium silicide ($TiSi_2$), and cobalt silicide ($CoSi_2$).

12. The apparatus of claim 11, further comprising a layer of conformal etch stop material on the layer of silicide material, wherein the layer of etch stop material comprises one of silicon dioxide (SiO_2), phosphosilicate glass (PSG, a Phosphorous doped SiO_2), silicon nitride (Si_3N_4), and silicon carbide (SiC).

13. The apparatus of claim 12, further comprising a layer of dielectric material comprising on the layer of conformal etch stop material, wherein the layer of dielectric material comprises one of carbon doped oxide (CDO), cubic boron nitride (CBN), silicon dioxide (SiO_2), phosphosilicate glass (PSG), silicon nitride (Si_3N_4), fluorinated silicate glass (FSG), and silicon carbide (SiC).

14. An apparatus comprising:

a substrate;

a device on the substrate including a gate electrode on a top surface of the substrate and a first junction region and a second junction region in the substrate adjacent the gate electrode; and

a silicon alloy material having a silicon alloy lattice spacing that is different than a lattice spacing of the substrate disposed in each of the first junction region and the second junction region such that a surface of the first junction region and a surface of the second junction region are superior to the top surface of the substrate by a length sufficient to cause a strain in the substrate.

15. The apparatus of claim 14, wherein the substrate comprises an N-type channel/well material of one of silicon, polycrystalline silicon, and single crystal silicon having an electrically negative charge, and wherein the silicon alloy material comprises a P-type junction region material having an electrically positive charge.

16. The apparatus of claim 15, wherein the silicon alloy is silicon germanium having a lattice spacing that is larger than a lattice spacing of the N-type channel/well material, and wherein the strain is a compressive strain.

17. A method comprising:

forming a device on a substrate, the device including:

a gate electrode on a surface of the substrate;

a first junction region and a second junction region in the substrate adjacent the gate electrode; and

depositing a silicon alloy material in each of the first junction region and the second junction region such that a surface of the first junction region and a surface of the second junction region are in a non-planar relationship with the surface of the substrate.

18. The method of claim 17, wherein depositing the silicon alloy material comprises depositing a sufficient thickness of silicon alloy material having a larger lattice spacing than a lattice spacing of the substrate to cause a compressive strain in the range between 0.5 percent compression and 2.5 percent compression in the substrate.

19. The method of claim 17, wherein depositing the silicon alloy material comprises a chemical vapor deposition sufficient to form an epitaxial layer of silicon alloy material.

20. The method of claim 17, wherein depositing the silicon alloy material comprises depositing silicon alloy material in the first junction region superjacent to a first substrate sidewall surface of the substrate proximate to the first junction region, and depositing silicon alloy material in the second junction region superjacent to a second substrate sidewall surface of the substrate proximate to the second junction region.

21. The method of claim 17, further comprising doping the substrate material with one of phosphorous, arsenic, and antimony to form an N-type channel/well material having an electrically negative charge.

22. The method of claim 17, further comprising doping the silicon alloy material with one of boron and aluminum to form a P-type junction region material having an electrically positive charge.

23. The method of claim 17, further comprising forming a layer of silicide material on the surface of the first junction region, the surface of the second junction region, and the gate electrode.

24. The method of claim 23, further comprising forming a sufficient layer of conformal etch stop material on the layer of silicide material to cause a tensile strain in the channel.

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