



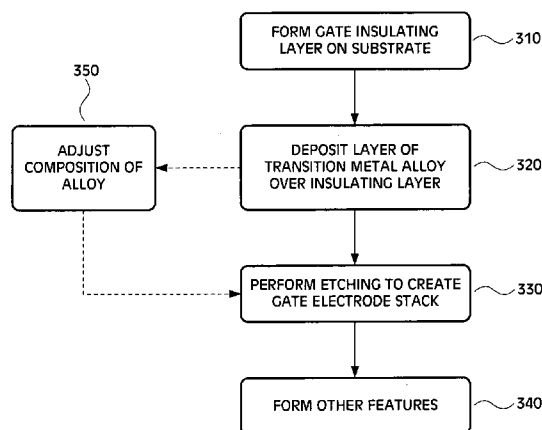
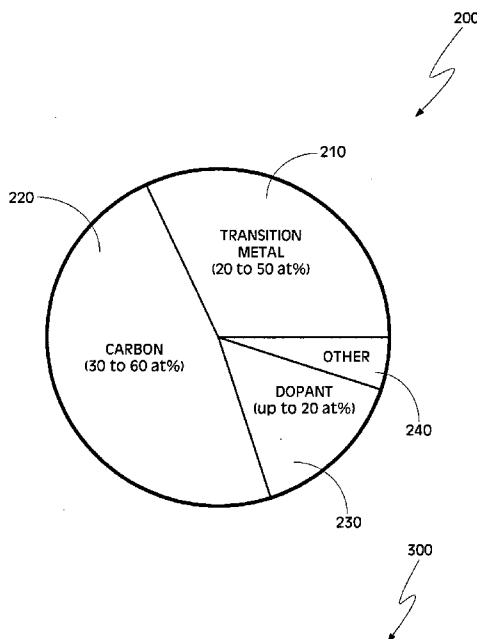
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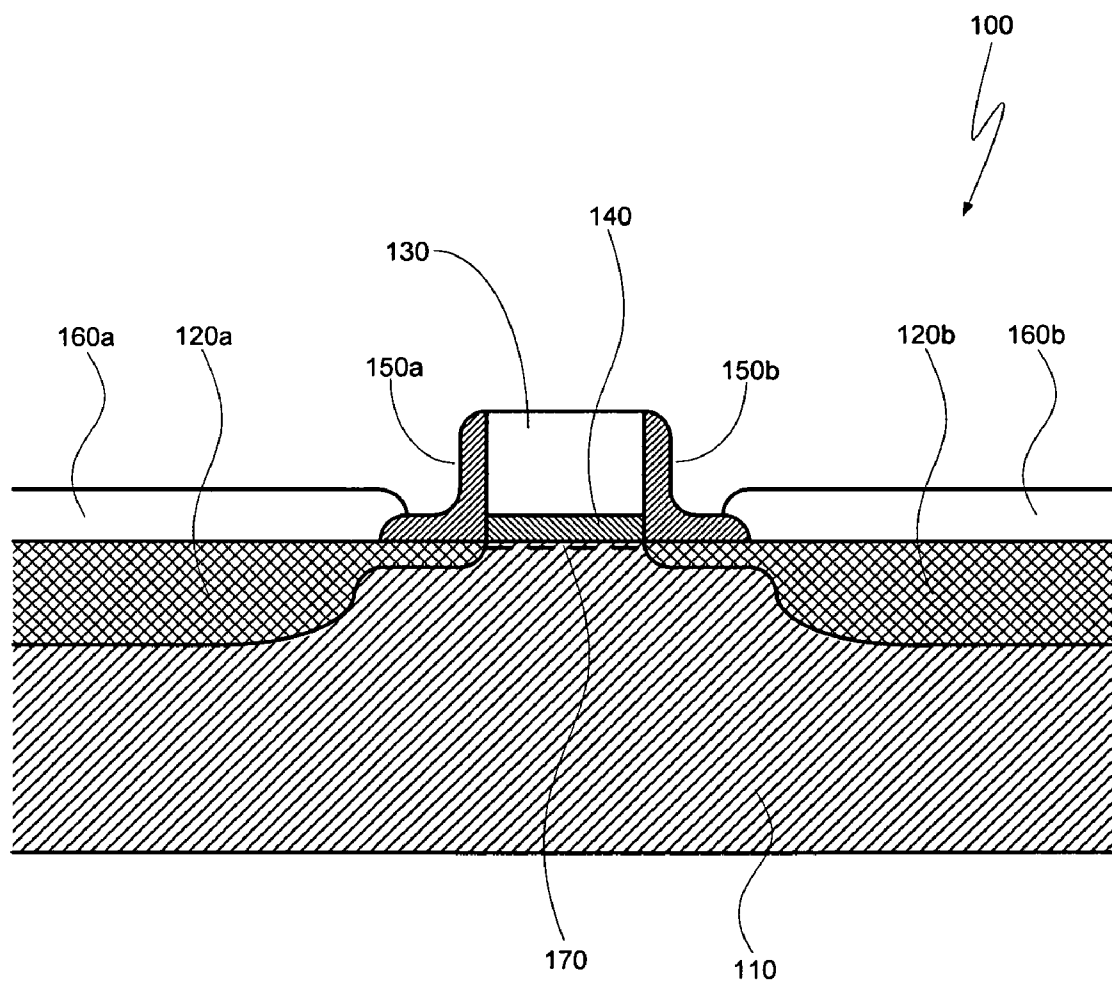
(19) **United States**(12) **Patent Application Publication** (10) **Pub. No.: US 2007/0096163 A1**  
(43) **Pub. Date: May 3, 2007**(54) **TRANSITION METAL ALLOYS FOR USE A  
GATE ELECTRODE AND DEVICE  
INCORPORATING THESE ALLOYS**(76) Inventors: **Mark Doczy**, Beaverton, OR (US);  
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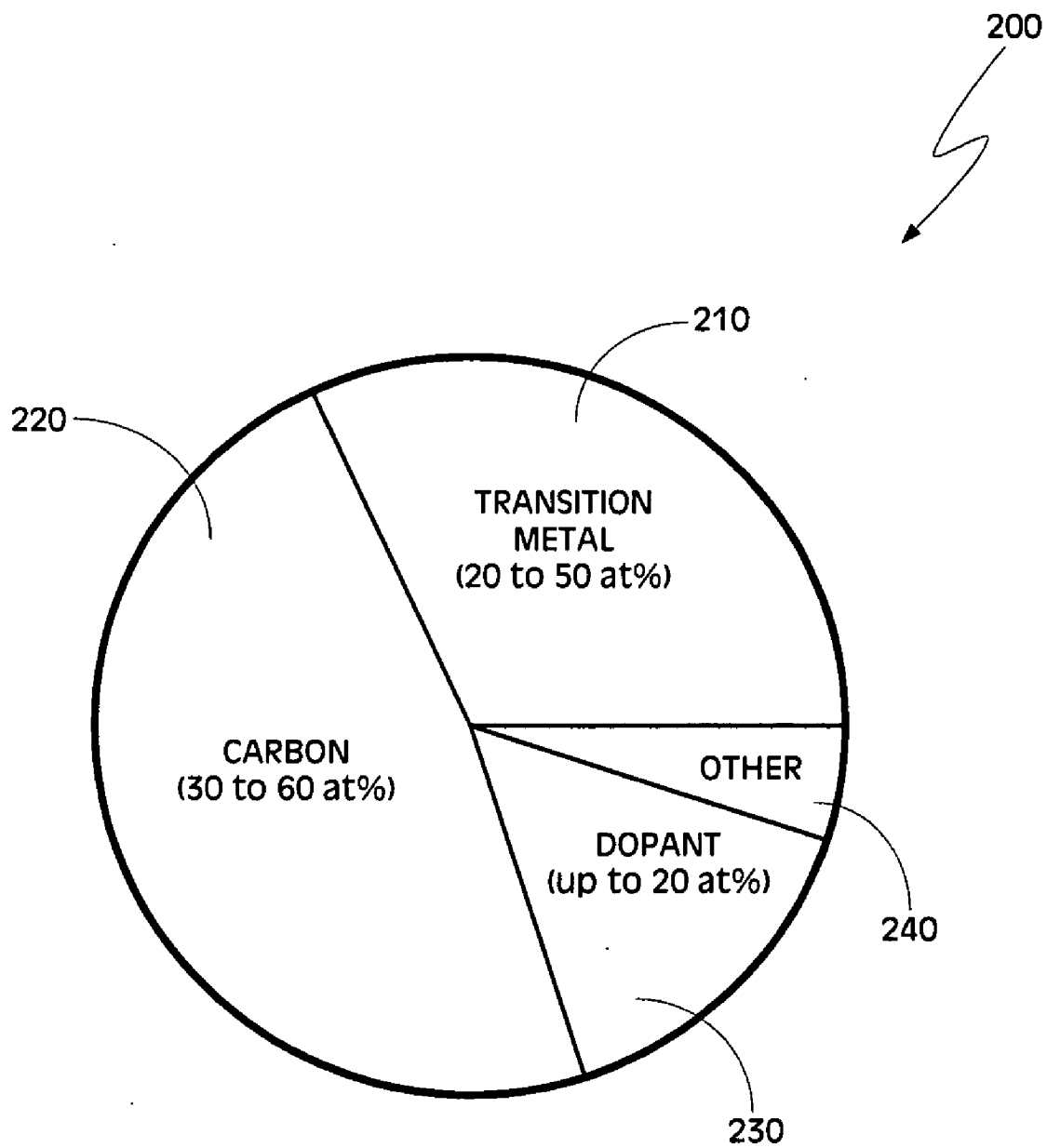
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**12400 WILSHIRE BOULEVARD, SEVENTH  
FLOOR**  
**LOS ANGELES, CA 90025-1030 (US)**(21) Appl. No.: **11/640,034**(22) Filed: **Dec. 15, 2006****Related U.S. Application Data**(62) Division of application No. 10/641,848, filed on Aug.  
15, 2003, now Pat. No. 7,030,430.**Publication Classification**(51) **Int. Cl.**  
**H01L 29/768** (2006.01)  
**H01L 27/148** (2006.01)  
(52) **U.S. Cl.** ..... **257/249**(57) **ABSTRACT**

Embodiments of a transition metal alloy having an n-type or p-type work function that does not significantly shift at elevated temperature. The disclosed transition metal alloys may be used as, or form a part of, the gate electrode in a transistor. Methods of forming a gate electrode using these transition metal alloys are also disclosed.





*FIG. 1 (PRIOR ART)*



*FIG. 2*

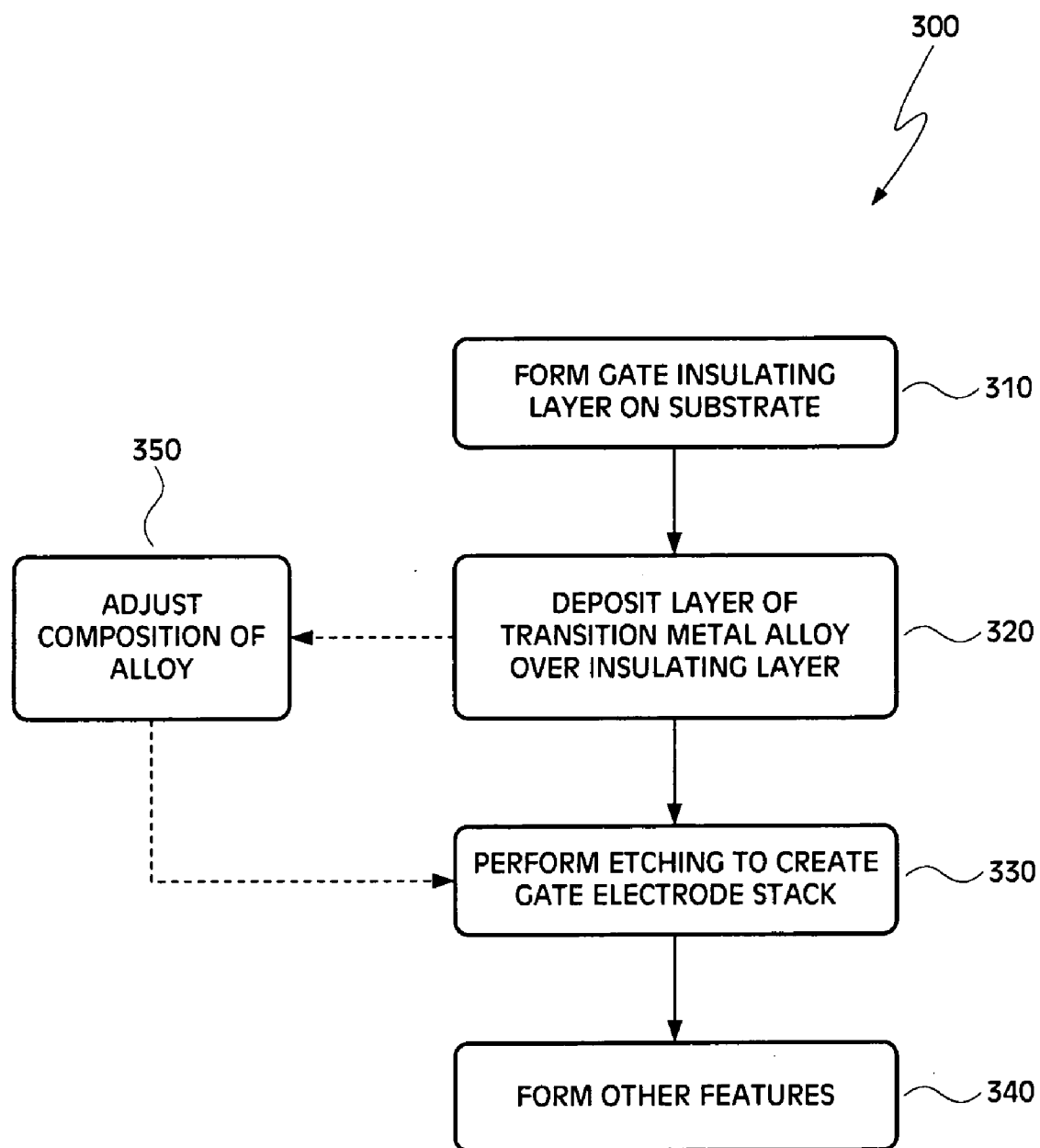
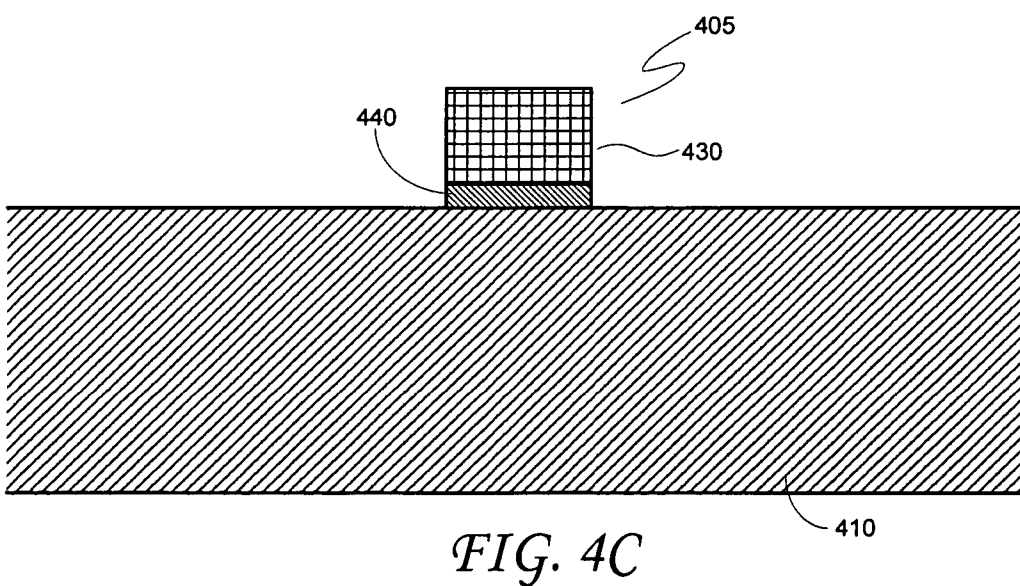
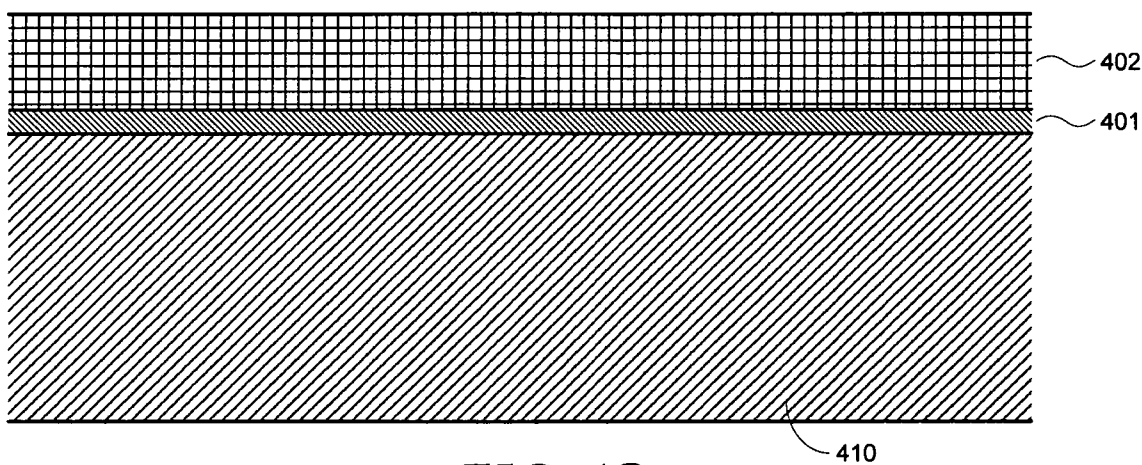
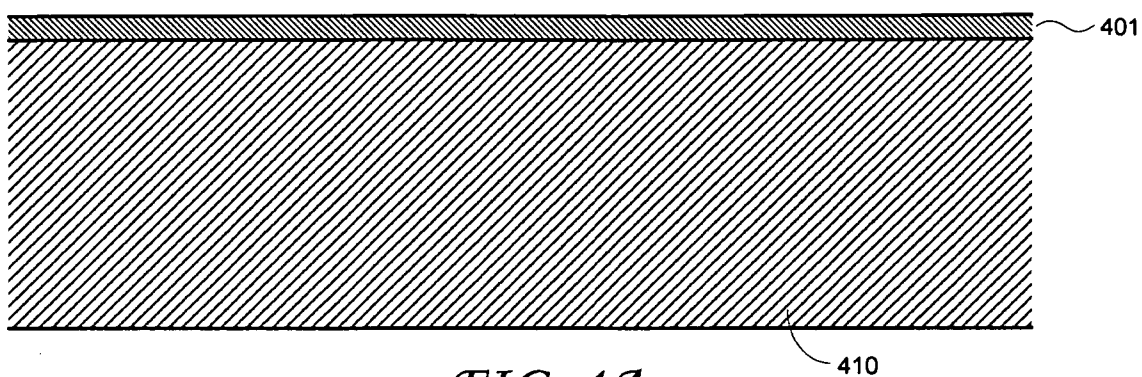


FIG. 3



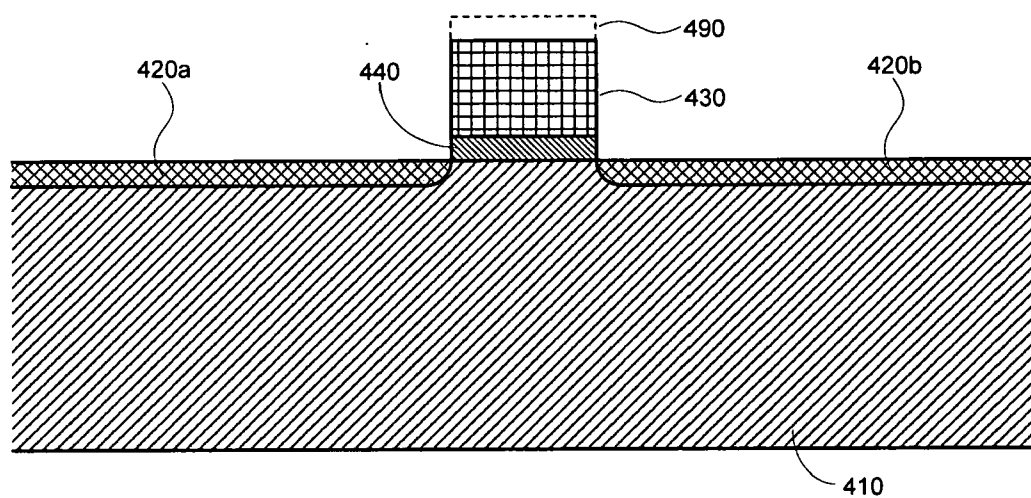


FIG. 4D

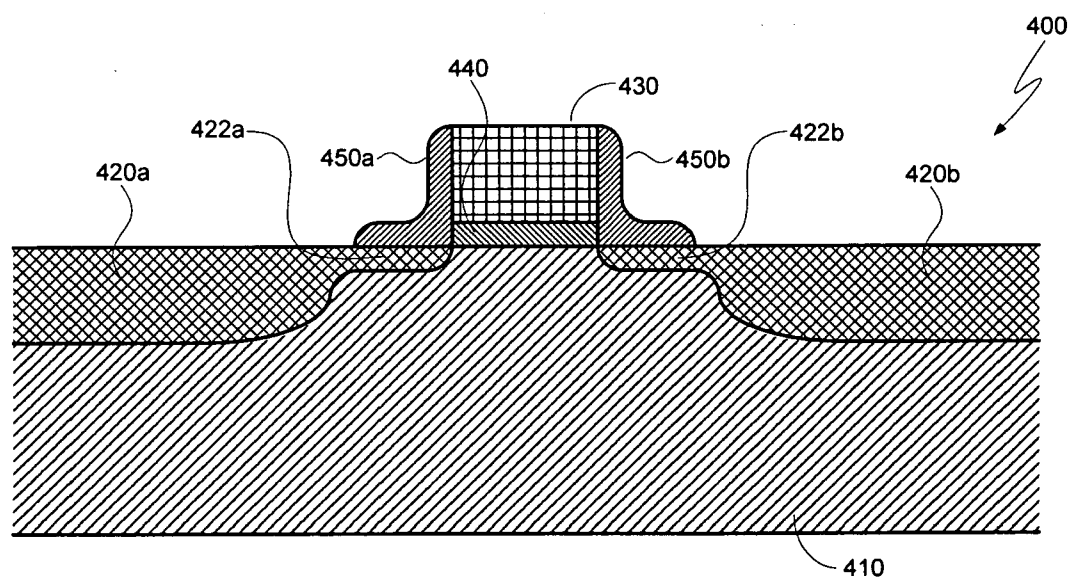


FIG. 4E

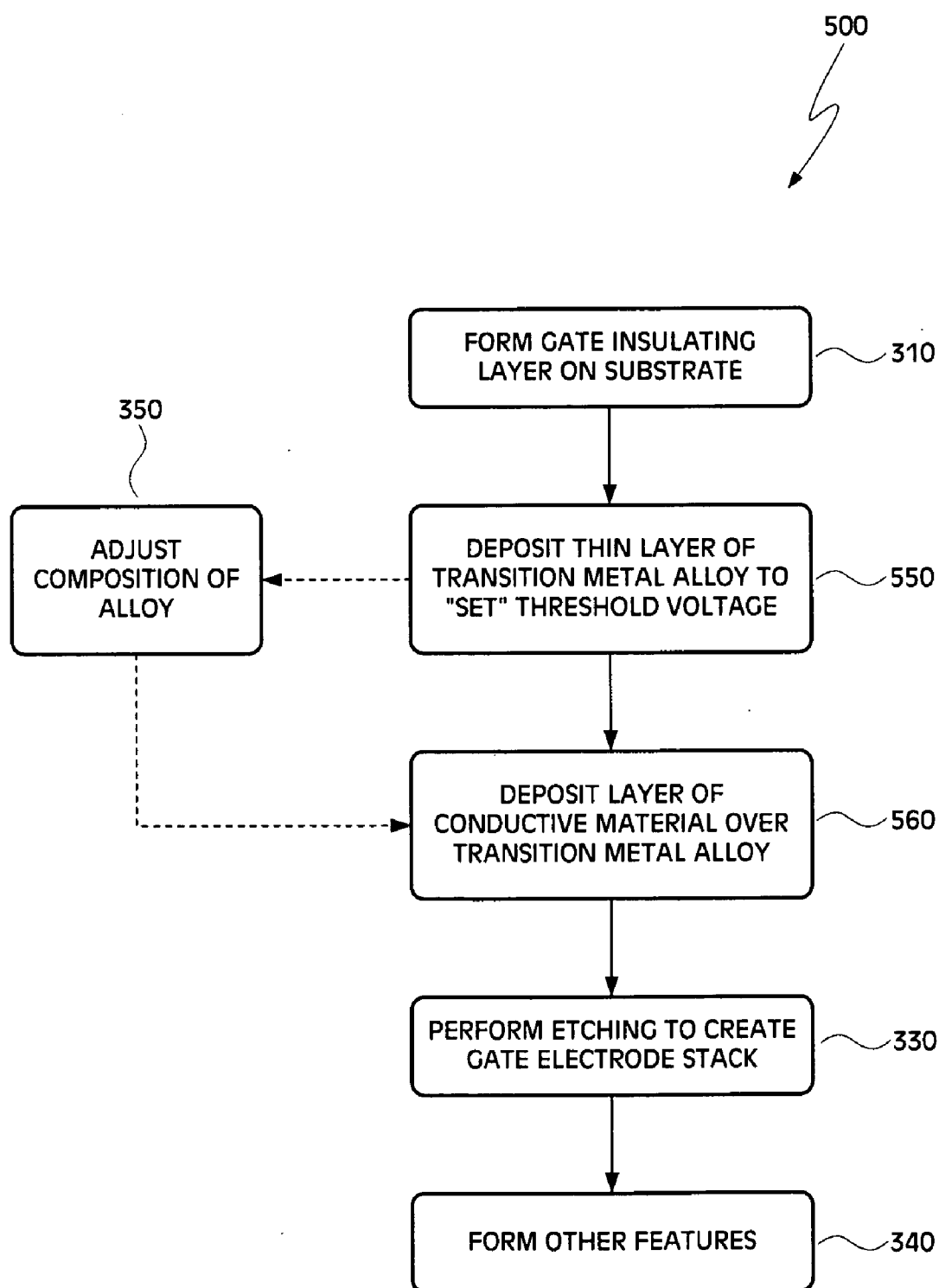


FIG. 5

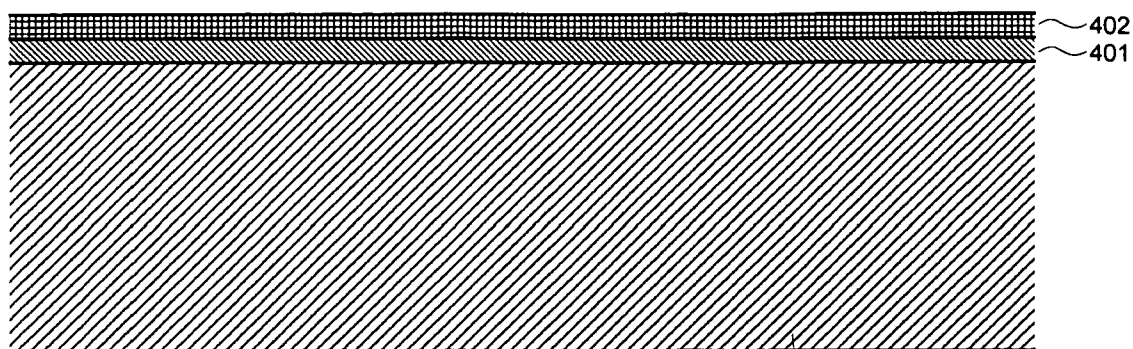


FIG. 6A

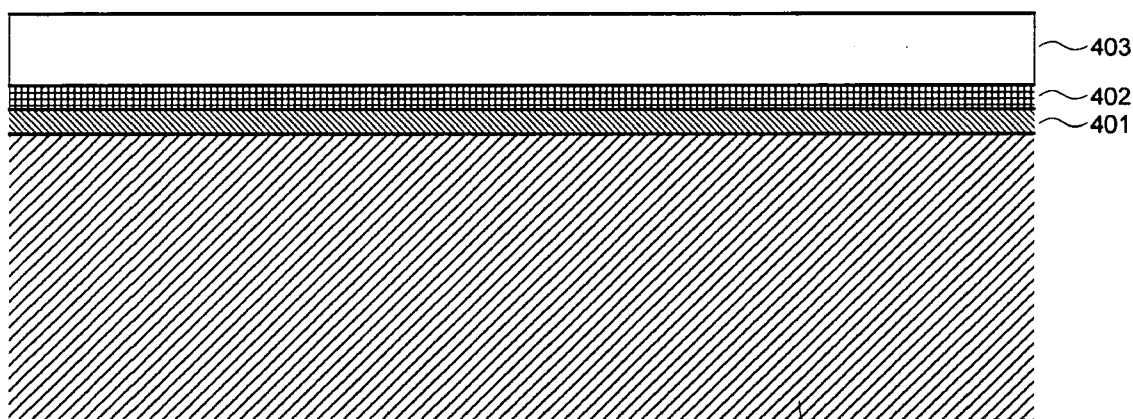


FIG. 6B

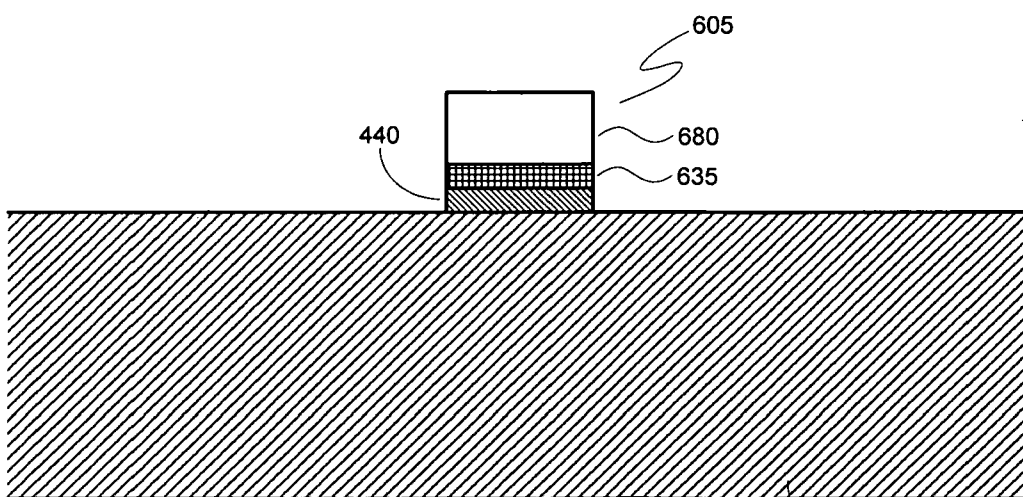


FIG. 6C



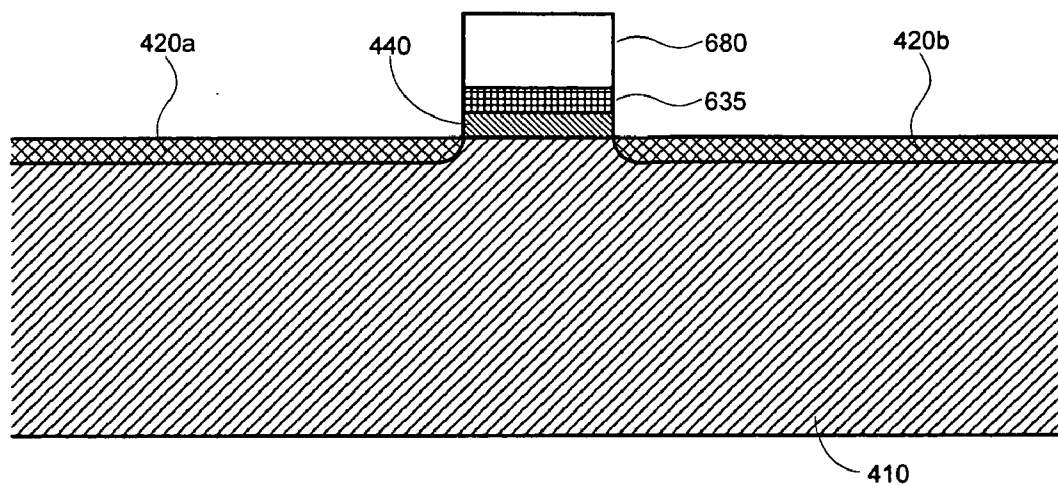


FIG. 6D

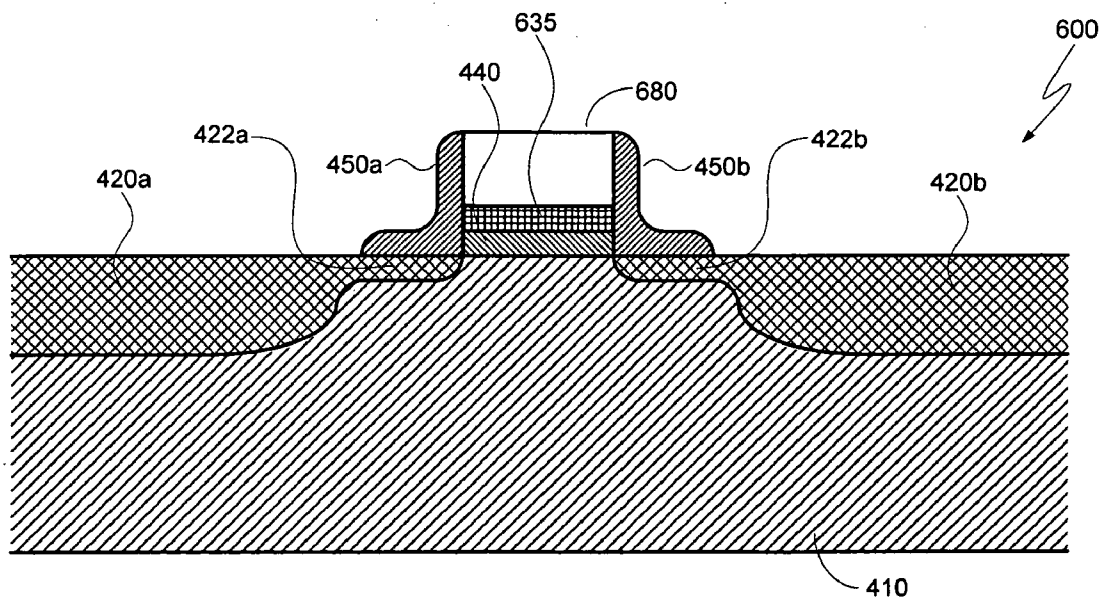


FIG. 6E

# TRANSITION METAL ALLOYS FOR USE A GATE ELECTRODE AND DEVICE INCORPORATING THESE ALLOYS

## FIELD OF THE INVENTION

[0001] The invention relates generally to integrated circuit devices and, more particularly, to metal alloys that can be used as a gate electrode in a transistor.

## BACKGROUND OF THE INVENTION

[0002] Illustrated in FIG. 1 is a conventional MOSFET (Metal Oxide Semiconductor Field Effect Transistor) 100. For an n-type MOSFET, the transistor 100 includes n-type source and drain regions 120a, 120b, respectively, formed in a p-doped substrate 110. A gate electrode 130 is disposed between the source and drain regions 120a, 120b, this gate electrode being separated from the substrate 110 and the source and drain regions 120a-b by a gate insulating layer 140. Insulating layers 150a, 150b further isolate the gate electrode 130 from the surrounding structures. Conductors 160a, 160b (e.g., conductive traces) may be electrically coupled with the source and drain regions 120a, 120b, respectively. If a sufficient voltage is applied to the gate electrode—i.e., the “threshold voltage”—electrons will flow from the source to the drain, these mobile electrons concentrated in a thin “inversion layer” 170 extending between the source and drain regions 120a, 120b. Of course, those of ordinary skill in the art will recognize that the complementary MOSFET—i.e., the p-type MOSFET—will have a similar structure (p-type source and drain regions on an n-type substrate), and that a CMOS (Complementary Metal Oxide Semiconductor) integrated circuit will utilize both n-type and p-type MOSFETs (or, more generally, both NMOS and PMOS devices).

[0003] In conventional MOSFET devices, the gate electrode 130 typically comprises a poly-silicon material, whereas the gate insulating layer comprises Silicon Dioxide (SiO<sub>2</sub>). To increase circuit density and improve device performance, it may be desirable to scale down the thickness of the gate insulating layer 140 (often referred to as the “gate oxide”). As the thickness of the gate oxide is scaled down, it may be necessary to use a material having a higher dielectric constant—i.e., a “high-k dielectric”—as the gate oxide in order to maintain sufficient capacitance while also preventing failure by electron tunneling. Integration of a poly-silicon gate electrode onto a high-k gate oxide has, however, proven difficult due to interactions between the poly-silicon gate material and the high-k insulating material. Furthermore, as the thickness of the gate insulating layer 140 is further scaled down (e.g., below about 20 Angstroms), it may be desirable to use an alternative material to poly-silicon as the gate electrode, in order to eliminate the thickness contribution of poly depletion to the gate oxide (i.e., to eliminate that portion of a poly-silicon gate electrode that becomes depleted of free charges and, hence, adds to the effective thickness of the gate insulating layer).

[0004] Use of a metal gate electrode can eliminate the above-described effects of depleted poly-silicon in the gate electrode, and a metal gate electrode may also enable further scaling down of the gate oxide thickness. However, use of metal materials as the gate electrode in NMOS and PMOS devices has also proven difficult. To optimize the perfor-

mance of a transistor, the metal used at the gate electrode should be selected to provide a work function that will achieve a sufficiently low (but non-zero) threshold voltage for the transistor (e.g., 0.2 V to 0.3 V). Many metals have a suitable work function (a value representing an energy level of the most energetic electrons within the metal), but are thermally unstable at high temperature. Process flows for transistors can often reach temperatures of 900° C. and, therefore, during subsequent processes, the work function of these metals may shift to unsuitable values. Furthermore, at elevated temperatures, these metal gate materials may react with the gate insulating layer, thereby degrading its insulating properties. Other metals are thermally stable at the temperatures present in transistor process flows; however, these metals have work functions that are inadequate for high performance transistors.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 is a schematic diagram illustrating an embodiment of a conventional MOSFET transistor.

[0006] FIG. 2 is a schematic diagram illustrating the composition of one embodiment of a transition metal alloy that can be used as a gate electrode.

[0007] FIG. 3 is a block diagram illustrating one embodiment of a method of forming a gate electrode including a transition metal alloy.

[0008] FIGS. 4A-4E are schematic diagrams illustrating further embodiments of the method of forming a gate electrode, as shown in FIG. 3.

[0009] FIG. 5 is a block diagram illustrating another embodiment of a method of forming a gate electrode including a transition metal alloy.

[0010] FIGS. 6A-6E are schematic diagrams illustrating further embodiments of the method of forming a gate electrode, as shown in FIG. 5.

## DETAILED DESCRIPTION OF THE INVENTION

[0011] For high performance transistors, it is desirable to have a low, but non-zero, threshold voltage—i.e., the gate voltage at which electrons (or, in the case of p-type devices, holes) begin to flow between the source and drain regions. Many factors can effect the threshold voltage of a transistor, and one of these factors is the work function of the gate electrode material. However, for many transistor designs, most of the other factors that can effect the threshold voltage are “locked in” by design constraints, such that the primary factor determining the transistor’s threshold voltage is the work function of the gate electrode. Thus, selection of the gate electrode work function plays a significant role in setting the threshold voltage of an optimized, high performance (e.g., high switching speed, high drive current, etc.) MOSFET device. As noted above, the “work function” of a material, such as a metal, describes the energy level of the most energetic electrons within the material.

[0012] The performance of a transistor is governed not so much by the absolute value of the gate electrode material’s work function, but rather by the relationship between the gate electrode’s work function and the work function of the underlying substrate material (e.g., Silicon, Gallium Ars-

enide, Silicon on insulator, etc.). Negative channel semiconductor devices—i.e., those that rely on the movement of electrons during activation—require an “n-type work function”, whereas positive channel semiconductor devices—i.e., those that rely on the movement of electron vacancies, or holes, during activation—require a “p-type work function.” A gate electrode has an n-type work function if the electrode material’s work function is near (e.g., within  $\pm 0.3$  eV) of the energy level of the underlying substrate material’s conduction band. Conversely, a gate electrode has a p-type work function if the electrode material’s work function is near the energy level of the substrate material’s valence band. Generally, for semiconductor materials, the valence band is the highest range of electron energies where electrons are normally present, whereas the conduction band is a range of electron energies above the valence band where electrons are free to accelerate under application of an electric field (and, thus, create an electric current).

[0013] By way of example, Silicon has a conduction band energy level of approximately 4.1 eV and a valence band energy level of approximately 5.2 eV. Thus, for a Silicon substrate, the gate electrode of a negative channel MOSFET (or NMOS) device would have an n-type work function of approximately 4.1 eV ( $\pm 0.3$  eV), and the gate electrode of a positive channel MOSFET (or PMOS) device would have a p-type work function of approximately 5.2 eV ( $\pm 0.3$  eV). Note that energy levels falling between the valence band and conduction band energy levels are often referred to as “midgap” energies (e.g., returning to the above example using Silicon, the midgap energies are those falling between approximately 4.4 and 4.9 eV). Also, the difference between the work function of the gate electrode material and the work function of the substrate material is often referred to as the “flatband” energy. However, because the work function of the substrate is often fixed—i.e., it is one of the “locked in” features of a transistor design—the term “flatband” is sometimes used in a manner that is synonymous with the term “work function.”

[0014] Disclosed herein are embodiments of a transition metal alloy having either an n-type work function or a p-type work function. The disclosed transition metal alloys may be used as the gate electrode in CMOS integrated circuits, and embodiments of methods of forming a gate electrode using such a transition metal alloy are also disclosed below. In one embodiment, the transition metal alloys are thermally stable at elevated temperatures (e.g., greater than 900° C.)—i.e., their work function does not shift or, in other words, there is no appreciable flat band shift. In another embodiment, the transition metal alloys, when used as a gate electrode, do not react with the underlying gate insulating layer at elevated temperature. In a further embodiment, a transition metal alloy comprises a transition metal carbide.

[0015] Turning now to FIG. 2, illustrated is one embodiment of a transition metal alloy **200** that may have an n-type work function—or, alternatively, a p-type work function—that is suitable for use as a gate electrode in MOSFET devices (e.g., either n-type or p-type). The transition metal alloy **200** includes a transition metal **210**, Carbon (C) **220** (or other suitable element, as described below), and a dopant **230**.

[0016] Generally, the transition metal **210** is selected to provide either an n-type work function or a p-type work

function. In one embodiment, the transition metal comprises one of Titanium (Ti), Tantalum (Ta), Zirconium (Zr), and Hafnium (Hf). In another embodiment, the transition metal may comprise any one of the aforementioned elements or one of Chromium (Cr), Molybdenum (Mo), Tungsten (W), Vanadium (V), and Niobium (Nb). In one embodiment, the transition metal **210** comprises between 20 and 50 atomic percent (“at %”) of the alloy **200**. In yet another embodiment, the alloy **200** includes two or more of the above-listed transition metals.

[0017] Carbon **220** may be another component of the transition metal alloy **200**. In one embodiment, carbon comprises between 30 and 60 at % of the alloy **200**. Some transition metals, when alloyed with Carbon to form a transition metal carbide (or other alloy including Carbon with no or minimal amounts of carbide), will be characterized by good thermal stability—i.e., at least some material properties of these transition metal carbides, such as the work function, do not degrade at elevated temperature. It should be understood, however, that Carbon is but one example of an element that can be alloyed with a transition metal to improve thermal characteristics. In addition to Carbon, other elements that may be alloyed with a transition metal to achieve enhanced thermal properties include, for example, Nitrogen (N), Silicon (Si), Germanium (Ge), and Boron (B), or various combinations of these elements.

[0018] The transition metal alloy **200** also includes a dopant **230**, as noted above. The dopant is introduced into the transition metal alloy to adjust or alter certain characteristics of the alloy. In one embodiment, the dopant is added to effect the work function of the alloy (e.g., to enhance either the n-type or p-type work function characteristics). In another embodiment, the dopant is added to alter another property of the transition metal alloy, such as conductivity. The dopant may, in one embodiment, comprise up to 20 at % of the transition metal alloy. In one embodiment, the dopant comprises Aluminum (Al)—e.g., for an n-type work function—and in another embodiment, the dopant comprises Platinum (Pt)—e.g., for a p-type work function. Other possible dopants include Silicon, Gallium (Ga), and Germanium (Ge), as well as many of the transition metals.

[0019] As shown in FIG. 2, the transition metal alloy **200** may further include other, residual substances **240**. The residual elements are typically present in the transition metal alloy in relatively small amounts as a result of the deposition process or other fabrication steps. In one embodiment, the residual substances comprise approximately 5 at % or less of the alloy’s composition. Common residual substances include Nitrogen and Oxygen, as well as halide impurities such as chloride. It should, however, be understood, as suggested above, that elements such as Nitrogen may be a desired component of the alloy **200** in other embodiments.

[0020] In one embodiment, the transition metal alloy **200** is a transition metal carbide comprising between 20 and 50 at % Titanium, between 30 and 60 at % Carbon, and up to 20 at % Aluminum. Such a transition metal carbide may provide an n-type work function. In a further embodiment, the transition metal carbide comprises approximately 37 at % Titanium, approximately 55 at % Carbon, and approximately 4 at % Aluminum, as well as approximately 4 at % Oxygen and 1 at % or less Nitrogen. Of course, those of

ordinary skill in the art will appreciate that these are but a few examples of transition metal alloys that may be useful as a gate electrode material.

[0021] In one embodiment, the transition metal alloy **200** is thermally stable at elevated temperature, and in a further embodiment, the transition metal alloy **200** has a thermally stable work function at elevated temperature, as measured on a high-k dielectric gate material, such as  $\text{ZrO}_2$ ,  $\text{HfO}_2$ , or  $\text{Al}_2\text{O}_3$ . In one embodiment, the transition metal alloy **200** exhibits thermal stability—e.g., the alloy's work function does not shift to a midgap energy level—at a temperature up to approximately  $900^\circ\text{C}$ . When the transition metal alloy **200** is used as a gate electrode in a MOSFET device, this enhanced thermal stability enables the gate electrode structure to withstand the high post-deposition processing temperatures that such device are routinely subjected to in the manufacturing process. Thus, the work function—and ultimately the performance—of the transistor will not degrade during later stages of a CMOS process flow.

[0022] Illustrated in FIG. 3 is an embodiment of a method **300** of forming a gate electrode using a transition metal alloy. Also, the method **300** of FIG. 3 is further illustrated by the schematic diagrams of FIGS. 4A through 4E, and reference should be made to these figures, as called out in the text.

[0023] Referring to block **310** in FIG. 3, a gate insulating layer is deposited on a substrate. This is illustrated in FIG. 4A, which shows a layer of gate insulating material **401** that has been deposited on a surface of a substrate **410**. In one embodiment, the gate insulating material **401** comprises a high-k dielectric material, such as  $\text{ZrO}_2$ ,  $\text{HfO}_2$ , or  $\text{Al}_2\text{O}_3$ . The layer of gate insulating material **401** may be deposited using any suitable technique. In one embodiment, the gate insulating material layer **401** is formed by a blanket layer deposition process, such as chemical vapor deposition (CVD) or physical vapor deposition (PVD).

[0024] In one embodiment, where an NMOS device is to be formed, the substrate **410** comprises a p-doped substrate (and the source and drain regions that are formed will comprise n-doped regions). In another embodiment, where a PMOS device is to be formed, the substrate **410** comprises an n-doped substrate (and the source and drain regions that are formed will comprise p-doped regions). In one embodiment, the substrate **410** comprises Silicon (e.g., single crystal Silicon); however, it should be understood that, in other embodiments, the substrate **410** may comprise another material (e.g., GaAs, Silicon-on-insulator, etc.).

[0025] A layer of a transition metal alloy is then deposited over the gate insulating material layer, as set forth in block **320**. This is illustrated in FIG. 4B, where a layer of a transition metal alloy **402** has been formed over the layer of gate insulating material **401**. In one embodiment, the layer of transition metal alloy **402** comprises the transition metal alloy **200** shown and described above with respect to FIG. 2. In a further embodiment, the layer of transition metal alloy **402** comprises a transition metal carbide and, in yet another embodiment, the transition metal alloy layer **402** comprises a transition metal carbide including Titanium, Carbon, and Aluminum. In yet a further embodiment, the transition metal alloy layer **402** comprises approximately 37 at % Titanium, 55 at % Carbon, and 3 at % Aluminum, as well as approximately 4 at % Oxygen and 1 at % or less Nitrogen.

[0026] The transition metal alloy layer may be deposited using any suitable technique. In one embodiment, the transition metal alloy layer **402** is deposited to a thickness of between approximately 500 and 2,000 Angstroms. The transition metal alloy layer **402** is, in one embodiment, deposited by a PVD process using a TiC(Al) target in a single chamber having an Argon gas environment (introduced at a flow rate of 10-200 sccm) at a pressure of between 1 and 100 mTorr with the substrate maintained at a temperature between  $0^\circ$  and  $450^\circ\text{C}$ . Deposition may take place using a DC power source in the 1 kW to 40 kW range and, in another embodiment, pulsed DC power at a frequency of between 1 and 100 kHz is utilized. In a further embodiment, the gate electrode material is deposited by a PVD process using a Ti(Al) target in a first chamber and a Carbon target in a second chamber, wherein the gate electrode is formed by alternating thin (e.g., 5-10 Angstroms) layers of Ti(Al) and Carbon (e.g., 5-10 Angstrom layers to a final thickness of between 500 and 2,000 Angstroms).

[0027] In another embodiment, the transition metal alloy layer **402** is deposited by a CVD process. Deposition is performed in a CVD chamber at a pressure of 0.25 to 10.0 Torr and at a temperature of between  $150^\circ\text{C}$ . and  $600^\circ\text{C}$ . Precursors introduced into the deposition chamber include  $\text{TiCl}_4$  vapor at a flow rate of 10 to 1000 sccm, TMA (trimethylaluminum, or  $\text{Al}(\text{CH}_3)_3$ ) vapor at a flow rate of 10 to 1000 sccm, as well as ammonia ( $\text{NH}_3$ ) at a flow rate up to 10 sccm. Also, an inert gas, such as  $\text{N}_2$ , Argon (Ar), or Helium (He), may be introduced into the deposition chamber (e.g., as either a transport agent or as a purging agent) at a flow rate up to 4,000 sccm.

[0028] In yet a further embodiment, the transition metal alloy layer **402** is deposited using an atomic layer deposition (ALD) process.

[0029] Returning to FIG. 3, etching is then performed to create the gate electrode stack, as set forth at block **330**. This is illustrated in FIG. 4C, where both the transition metal alloy layer **402** and gate insulating material layer **401** have been etched to create a gate electrode stack **405**. The gate electrode stack includes a gate electrode **430** overlying a gate insulating layer **440**. Any suitable etching processes may be employed to etch the transition metal alloy layer **402** and gate insulating material layer **401** in order to form the gate electrode **430** and gate insulating layer **440**. Although not shown in the figures, it will be appreciated by those of ordinary skill in the art that a patterned mask layer may be formed prior to etching.

[0030] Referring to block **340**, additional features may then be formed on the substrate to create an NMOS or PMOS device. This is illustrated in FIGS. 4D and 4E, where additional features have been created to form a device **400**. Referring first to FIG. 4D, source and drain regions **420a**, **420b** are created. For an NMOS transistor, the source and drain regions **420a**, **420b** will comprise n-type regions, whereas for a PMOS transistor, the source and drain regions will comprise p-type regions. An ion implantation process may be employed to create the source and drain regions **420a**, **420b**. Depending upon the composition of the gate electrode **430**, it may be desirable to deposit a hard mask layer **490** (shown in dashed line) over the gate electrode **430** during ion implantation in order to inhibit the implantation of ions at the gate electrode.

[0031] Turning to FIG. 4E, insulating layers **450a**, **450b** have been formed, and further ion implantation has been performed to create deeper source and drain regions **420a**, **420b**. The insulating layers **450a**, **450b** also function as masks to inhibit the implantation of ions in the underlying substrate **410**, thereby forming source and drain extensions **422a**, **422b**, respectively. Ion implantation on the gate electrode material may be inhibited using a hard mask, as noted above. Other features that may be formed include conductive interconnects (e.g., see FIG. 1, items **160a-b**), as well as a passivation layer.

[0032] In an alternative embodiment, which is set forth in block **350** in FIG. 3, the composition of the transition metal alloy layer **402** is adjusted during the deposition process. As noted above, in one embodiment, the gate electrode may comprise alternating thin layers of different substances (e.g., Ti(Al) and C). Other variations in the deposition process (e.g., pressure, temperature, pulse rate, process sequences, precursors, etc.) may effect the final composition of the transition metal alloy. In one embodiment (see block **350**), variations in the deposition process are introduced to alter the composition of the transition metal alloy. For example, this additional alloying of the gate electrode material during deposition can be used to convert the work function—e.g., from an n-type to a p-type—which can provide for a simplified process flow (i.e., by avoiding deposition of two separate gate electrode materials for n-channel and p-channel devices). As will be appreciated by those of ordinary skill in the art, conversion of the work function is but one example of the gate electrode's characteristics that can be altered through this additional alloying and, further, that such variations in the deposition process can be used to adjust other chemical and electrical properties of the gate electrode material.

[0033] In the embodiments illustrated with respect to FIGS. 3 and 4A-4E, the transition metal alloy functions as a gate electrode. However, the disclosed transition metal alloys are not so limited in function and application. In addition to use as a conductor and gate electrode, the disclosed transition metal alloys may, in other embodiments, function as a barrier layer and/or an etch stop. Embodiments of the use of the disclosed transition metal alloys as a diffusion barrier and/or etch stop (as well as part of a gate electrode) are shown and described below with respect to FIGS. 5 and 6A through 6E.

[0034] Thus, turning now to FIG. 5, illustrated is another embodiment of a method **500** of forming a gate electrode using a transition metal alloy. The method **500** of FIG. 5 is further illustrated by the schematic diagrams of FIGS. 6A through 6E, and reference should be made to these figures, as called out in the text. Also, many of the drawing elements shown in FIGS. 5 and 6A-6E are the same or similar to those shown in FIGS. 3 and 4A-4E, respectively, and like reference numerals are used to refer to the same items in FIGS. 5 and 6A-6E.

[0035] Referring to block **310**, a layer of gate insulating material is formed on a substrate. This is illustrated in FIG. 6A, which shows a gate insulating material layer **401** that has been deposited on a substrate **410**, as described above. Again, the gate insulating material layer **401** may, in one embodiment, comprise a high-k dielectric material (e.g.,  $\text{ZrO}_2$ ,  $\text{HfO}_2$ ,  $\text{Al}_2\text{O}_3$ , etc.).

[0036] As set forth at block **550**, a relatively thin layer of a transition metal alloy is deposited over the gate insulating material layer to “set” the threshold voltage of the transistor. This is also illustrated in FIG. 6A, where a thin layer of a transition metal alloy **602** has been deposited over the gate insulating material layer **401**. In one embodiment, the thickness of the transition metal alloy layer **602** is between 25 and 100 Angstroms.

[0037] In one embodiment, the layer of transition metal alloy **602** comprises the transition metal alloy **200** shown and described above with respect to FIG. 2. In a further embodiment, the layer of transition metal alloy **602** comprises a transition metal carbide and, in yet another embodiment, the transition metal alloy layer **602** comprises a transition metal carbide including Titanium, Carbon, and Aluminum. In yet a further embodiment, the transition metal alloy layer **602** comprises approximately 37 at % Titanium, 55 at % Carbon, and 3 at % Aluminum, as well as approximately 4 at % Oxygen and 1 at % or less Nitrogen. The layer of transition metal alloy **602** may be deposited using any suitable blanket deposition technique, such as PVD, CVD, or ALD, as described above.

[0038] A layer of a conductive material is then deposited over the layer of transition metal alloy, as set forth in block **560**. This is illustrated in FIG. 6B, where a layer of conductive material **603** has been deposited over the transition metal alloy layer **602** to form a gate electrode. The conductive material layer **603** may comprise any suitable conductive material, such as poly-silicon or Aluminum. In one embodiment, the thickness of the conductive material layer **603** is between 500 and 2,000 Angstroms.

[0039] The conductive material layer **603** may be deposited using any suitable deposition technique. In one embodiment, the conductive material layer **603** is deposited using a blanket deposition process, such as CVD or PVD. In another embodiment, the conductive material layer **603** is deposited using a selective deposition technique. In this embodiment, the transition metal gate electrode and gate insulating layer are first patterned by etching, and the conductive material is selectively deposited on the transition metal gate electrode using a selective deposition technique, such as electroplating or electroless plating.

[0040] Etching is then performed to create the gate electrode stack, as set forth at block **330** in FIG. 5. This is illustrated in FIG. 6C, where both the conductive material layer **603**, transition metal alloy layer **602**, and gate insulating material layer **401** have each been etched to create a gate electrode stack **605**. The gate electrode stack **605** includes a conductive layer **680** overlying a transition metal alloy layer **635** which, in turn, overlies a gate insulating layer **440**. Any suitable etching processes may be employed to etch the conductive material, transition metal alloy, and gate insulating material layers **603**, **602**, **401**, respectively. Although not shown in the figures, it will be appreciated by those of ordinary skill in the art that a patterned mask layer may be formed prior to etching.

[0041] Additional features may then be formed on the substrate to create an NMOS or PMOS device, as set forth at block **340**. This is illustrated in FIGS. 6D and 6E, where additional features have been created to form a device **600**. With reference to FIG. 6D, source and drain regions **420a**, **420b** are created by ion implantation. As previously noted,

a hard mask may not be needed in this embodiment, where the conductive material layer **680** (e.g., poly-silicon) may itself function as a hard mask during ion implantation. Referring now to FIG. 6E, insulating layers **450a**, **450b** have been formed. Further ion implantation results in the formation of deeper source and drain regions **420a**, **420b**, and the insulating layers **450a**, **450b** inhibit the implantation of ions in the underlying substrate **410**, such that source and drain extensions **422a**, **422b** are created, all as described above. Other features that may be formed include conductive interconnects (e.g., see FIG. 1, items **160a-b**), as well as a passivation layer.

[0042] As suggested above, the disclosed transition metal alloys are not limited in function to their role as a conductor and gate electrode. In one embodiment, the disclosed transition metal alloys may further function as a barrier layer material and, in another embodiment, these transition metal alloys may function as an etch stop, as will now be described in more detail.

[0043] For some embodiments, the transition metal alloy **200** may not be a “good” conductor. In this case, it may be desirable to using a relatively thin layer of the transition metal alloy—as shown in FIG. 6C—to achieve a desired threshold voltage with the optimal work function characteristics of the transition metal alloy, and then form another layer on top of the transition metal alloy of a relatively good conductor, such as Aluminum. However, many metals such as Aluminum that are good conductors will react with (e.g., lose electrons to) the underlying gate insulator material. Thus, in this instance, the thin layer of transition metal alloy functions as a barrier layer.

[0044] In another embodiment, as noted above, a relatively thin layer of a transition metal alloy can function as an etch stop. As an etch stop, a thin transition metal alloy layer is again applied to “set” the threshold voltage of the transistor. A conductive material that more readily etches—e.g., poly-silicon—is then deposited over the thin transition metal alloy layer (see FIGS. 6B and 6C). Etching of the conductive layer (e.g., poly-silicon) stops at the thin transition metal alloy layer, and another etch process is performed to remove any remaining transition metal alloy. Materials such as poly-silicon are very amenable to anisotropic etching processes and, further, because the transition metal alloy layer is relatively thin as compared to the overall thickness of the gate electrode (i.e., the electrode stack including the transition metal alloy layer and the conductive material layer), this layer is easily to removed. Note also that poly-silicon can function as a hard mask material during ion implantation and, therefore, where the conductive material layer **680** comprises poly-silicon (or other similar material), a hard mask (see FIG. 4D, item **490**) may not be necessary during formation of the source and drain regions by ion implantation.

[0045] Embodiments of a transition metal alloy that may be used in the gate electrode of a transistor—as well as methods of forming a gate electrode for a transistor—having been herein described, those of ordinary skill in the art will appreciate the advantages of the disclosed embodiments. The disclosed transition metal alloys can function as a gate electrode in NMOS or PMOS devices, and these transition metal alloys are thermally stable—e.g., the alloy’s work function does not significantly shift nor does the alloy react

with the underlying insulating material—at temperatures up to 900° C. Thus, the disclosed transition metal alloys can be integrated into existing CMOS process flows, where processing temperatures can approach 900° C. Also, using one of the disclosed transition metal alloys as the gate electrode in a transistor allows for further scaling down of the thickness of the gate oxide. Further, in addition to functioning as a conductor and gate electrode, the disclosed transition metal alloys can also serve as a barrier layer and/or etch stop.

[0046] The foregoing detailed description and accompanying drawings are only illustrative and not restrictive. They have been provided primarily for a clear and comprehensive understanding of the disclosed embodiments and no unnecessary limitations are to be understood therefrom. Numerous additions, deletions, and modifications to the embodiments described herein, as well as alternative arrangements, may be devised by those skilled in the art without departing from the spirit of the disclosed embodiments and the scope of the appended claims.

1. An alloy comprising:

approximately 20 to 50 atomic percent of a transition metal, the transition metal selected from a group consisting of titanium, zirconium, tantalum, and hafnium;

approximately 30 to 60 atomic percent of carbon; and

up to approximately 20 atomic percent of aluminum.

2. The alloy of claim 1, wherein the alloy has a work function in a range of approximately 3.8 eV to 4.4 eV.

3. The alloy of claim 2, wherein the work function does not significantly shift at a temperature up to approximately 900° Celsius.

4. The alloy of claim 1, further comprising up to 5 atomic percent of a residual material, the residual material comprising at least one of oxygen, nitrogen, and chloride.

5. An alloy comprising:

approximately 20 to 50 atomic percent of a transition metal;

approximately 30 to 60 atomic percent of a combination of one or more elements, the combination of elements including at least one element selected from a group consisting of carbon, nitrogen, silicon, germanium, and boron; and

up to approximately 20 atomic percent of a dopant.

6. The alloy of claim 5, wherein the alloy has a work function of between approximately 3.8 eV to 4.4 eV.

7. The alloy of claim 5, wherein the alloy has a work function of between 4.9 eV and 5.5 eV.

8. The alloy of claim 5, wherein the alloy has a work function that does not significantly shift at a temperature up to approximately 900° Celsius.

9. The alloy of claim 5, wherein the transition metal is selected from a group consisting of titanium, zirconium, tantalum, hafnium, tungsten, chromium, molybdenum, vanadium, and niobium.

10. The alloy of claim 5, further comprising up to 5 atomic percent of a residual material, the residual material comprising at least one of oxygen, nitrogen, and chloride.

**11.** The alloy of claim 5, wherein the dopant is selected from a group consisting of aluminum, platinum, silicon, gallium, and germanium.

**12.** An alloy comprising:

approximately 37 atomic percent of titanium;

approximately 55 atomic percent of carbon; and

approximately 3 atomic percent of aluminum;

wherein the alloy has a work function of between approximately 3.8 eV and 4.4 eV.

**13.** The alloy of claim 12, wherein the work function does not significantly shift at a temperature up to approximately 900° Celsius.

**14.** The alloy of claim 12, further comprising approximately 4 atomic percent of oxygen and less than 1 atomic percent of nitrogen.

**15-45.** (canceled)

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