MOSFET STRUCTURE HAVING REDUCED GATE CAPACITANCE AND METHOD OF FORMING SAME

FIELD OF THE INVENTION

This invention relates to metal-oxide-semiconductor field effect transistors (MOSFETs) and, in particular, to an improved structure of a MOSFET having reduced gate capacitance and increased switching speed.

BACKGROUND OF THE INVENTION

It is generally desirable to construct electrical circuits capable of high speed operation. In an electrical circuit containing MOSFETs, this requires the MOSFETs themselves to have rapid response to input signals. A significant barrier to achieving higher operating speeds of MOSFETs has been overcoming the parasitic gate capacitance of the MOSFET, where a significant amount of delay is incurred while charging and discharging the gate of the MOSFET to a certain voltage in order to amplify a signal or to fully switch the MOSFET on and off.

Fig. 1a shows a representative vertical MOSFET with the gate-source parasitic capacitance (C_{GS}) and the gate-drain parasitic capacitance (C_{GD}) shown. Also shown in Fig. 1a is the drain-source parasitic capacitance (C_{DS}).

To operate the N channel MOSFET of Fig. 1a, a positive voltage V_{DD} is applied to drain terminal 20, while a low voltage (e.g., ground) is applied to source regions 30 and body regions 34. Source regions 30 and body regions 34, which constitute the emitter and base of a parasitic NPN bipolar transistor, are imperfectly shorted together by contacts 36 to prevent these regions from being forward biased. Conductive gate 38 is insulated from source regions 30 and body regions 34 by a

gate oxide. When a gate-source voltage V_{GS} is applied to gate 38 which exceeds the threshold voltage V_T of the MOSFET, an ohmic channel forms in body regions 34 under gate 38 so as to ohmically couple N-type source regions 30 to N-type drain 40. Current is then conducted between source contacts 36 and drain terminal 20. When the MOSFET is in its off state, a depletion region, represented by dashed outline 44, is created within drain 40.

A basic equivalent circuit for the MOSFET of Fig. 1a is shown in Fig. 1b. As shown in Fig. 1b, for the gate 50 to have a voltage V_G necessary to fully turn on MOSFET 52, both C_{GS} and C_{GD} must be fully charged. Capacitance C_{DS} will be considered herein to approximate zero. Also shown in Fig. 1b is input gate current I_G and current $I_{C_{GD}}$ charging capacitor C_{GD}. Note that source region 30, body region 34, and drain 40 form a parasitic NPN bipolar transistor within the MOSFET, as shown in Fig. 1b.

A vertical MOSFET, such as shown in Fig. 1a, is typically a polysilicon gate device, where the gate 38 is used as a diffusion mask to self-align source regions 30 and body regions 34.

Fig. 2 illustrates the voltage conditions during a dynamic switching operation for a representative MOSFET showing the effects of the charging of capacitances C_{GS} and C_{GD} with a constant current I_G applied at $t = 0$. In region 1 of the graph of Fig. 2, the MOSFET is off, with V_{GS} below the threshold voltage V_T. Input gate current I_G is shared between C_{GD} and C_{GS} according to their capacitance ratio. Within region 2, the threshold voltage V_T is reached and the MOSFET begins to turn on, lowering the drain-to-source voltage V_{DS}. This changing V_{DS} sets up a condition where the voltage is changing more rapidly across C_{GD} than C_{GS}. Current increases in C_{GD} and decreases in C_{GS}, thus reducing the rate at which V_{GS} is increasing. As V_{GS} becomes larger, the dv/dt of the drain-to-source voltage V_{DS} increases until the current

$I_{C_{GD}}$ charging C_{GD} reaches a magnitude equal to I_G, and V_{GS} no longer increases. This condition results in the flat portion of the V_{GS} curve in region 3 of Fig. 2.

During this time, the depletion region under the gate, generally shown as depletion region 44 in Fig. 1a, decreases since the potential of drain 40 under gate 38 is lowered due to this region being pulled down by the increasing ohmic channel between N-type source region 30 and N-type drain 40. During the entire turn-on period of the MOSFET, capacitance C_{GD} is increasing due to this narrowing of the effective insulation between the plates of the equivalent capacitor C_{GD}. As this capacitance increases, a decreasing dv/dt of the drain-to-source voltage V_{DS} results. This increase in capacitance C_{GD} is reflected in the curved lower portion of V_{DS} shown in Fig. 2.

Once capacitance C_{GD} has stabilized, the MOSFET is essentially fully on, and C_{GD} does not cause any further switching delay.

As seen by the gate charge characteristics of Fig. 2, the delay in switching of the MOSFET is significantly affected by capacitance C_{GD}, where capacitance C_{GD} is more commonly referred to as the reverse transfer capacitance (C_{rss}). Since, as shown in Fig. 2, capacitance C_{GD} is affected by voltage changes at the drain, it becomes understandable how the effective total gate capacitance (C_{in}) of the MOSFET under dynamic conditions is calculated using the following equation:

$$C_{in} = C_{GS} + C_{GD}\ (1 - A_V), \qquad \text{(eq. 1)}$$

where $A_V = dV_{DS}/dV_{GS}$.

For an N channel MOSFET, dV_{DS} will be a negative value, and for a P channel MOSFET, dV_{GS} will be a negative value. Thus, in either case, $(1-A_V)$ is equal to (1 + voltage gain).

It is also to be noted that essentially the same

gate charge characteristics are encountered with the discharging of the gate, which causes the turn-off speed of the MOSFET to be delayed. In linear applications, such as radio frequency (RF) power amplification, input capacitance largely determines the upper frequency limit of the MOSFET.

Typically, the value C_{GD} $(1-A_V)$ is at least three times greater than C_{GS}, and thus any reduction of capacitance C_{GD} will significantly lower the switching time of the MOSFET, or significantly raise the usable operating frequency.

Capacitance is calculated using the equation:

$$C = AKe_0/t, \text{ where} \qquad \text{(eq. 2)}$$

C is the capacitance;

e_0 is the permittivity of empty space (8.85×10^{-2} $coul^2/newton^2-m^2$);

K is the dielectric constant (3.9 for SiO_2 and 11.7 for Si);

A is the plate area; and

t is the dielectric thickness.

Thus, capacitance may be reduced by decreasing the plate area or increasing the dielectric thickness.

The prior art has attempted to reduce the parasitic gate capacitance of a MOSFET by reducing the area of the gate and/or increasing the effective dielectric thickness between the gate and the drain.

Two types of approaches which have been previously used to reduce C_{GD} are shown in Figs. 3 and 4 where, in Fig. 3, an increased thickness of dielectric 60 is formed over drain 62 to provide an increased dielectric thickness between gate 64 and drain 62. The gate-source capacitance C_{GS} is essentially unchanged, since the thickness of the dielectric separating gate 64 from source region 66 is essentially unchanged.

Prior art Fig. 4 illustrates an approach where

an N channel vertical MOSFET uses two separate gates 70 and 72 commonly connected to a gate voltage V_G. Since the effective area of the gate over drain 76 is decreased, the C_{GD} is also decreased.

One drawback of the MOSFET of prior art Fig. 3 is that gate 64 may be misaligned with respect to raised dielectric portion 60, causing part of the device to have low gain. In Fig. 4, a center portion of the gate oxide 70 over drain 76 must be masked and protected while body regions 78 and source regions 74 are formed self-aligned with the gate. Also in Fig. 4, the width of gate elements 72 is subject to mask and photoresist variations, which cause variations in C_{GD} across a wafer and from lot to lot. The critical masking steps required to form raised dielectric portion 60 in Fig. 3 and to perform the precise etching of the gate in Fig. 4 require a relatively precise alignment of the mask, or relatively precise process and mask control, thus inevitably resulting in lower yields and variable performance devices.

Another drawback to the MOSFET in Fig. 3 is the imperfect short across the emitter-base of the parasitic bipolar transistor. Under certain adverse conditions, the bipolar transistor may be turned on to the extent of causing secondary breakdown and device failure. Manufacturers have addressed this problem by: 1) reducing the depth of the N+ source diffusion to lower beta; 2) moving the P+ body contact region closer to the channel region to reduce resistance between the emitter and base; and 3) reducing the lateral dimension of the N+ source region to lower the resistance between the emitter and base.

What is needed in the art is a MOSFET structure having a relatively low C_{GD} and an inoperative parasitic bipolar transistor which may be formed with self-aligned source, body, and body contact regions and which may be formed without requiring numerous and difficult process steps.

SUMMARY OF THE INVENTION

The above-described disadvantages of the prior art MOSFETS have been overcome by the invention described herein. In accordance with one embodiment of the invention, a vertical MOSFET is formed having a lower gate portion overlying the channel region of the MOSFET and separated from the channel region by a thin gate oxide layer. An upper gate portion is formed overlying the drain of the MOSFET and separated from the drain by a relatively thick self-aligned oxide layer. In this particular embodiment, since the dielectric thickness between the upper gate portion and the drain is relatively large, the MOSFET exhibits a lower gate-drain capacitance (C_{GD}) value, while the threshold voltage of the MOSFET remains relatively unchanged. The upper gate portion may be electrically connected to the lower gate portion or may be electrically isolated from the lower gate portion. If the upper gate portion is electrically isolated from the lower gate portion, a separate gate voltage may be connected to the upper gate portion to allow the upper gate portion to either act as a field plate or act to augment the fields generated by the lower gate portion to enhance the current handling capabilities of the MOSFET. A preferred method of forming the resulting MOSFET having this lowered C_{GD} allows the source and body regions to be precisely aligned with the drain edge of the lower gate portion, and allows an ion implant damaged body contact region to be formed directly under, and self-aligned to, the source region, which ensures the parasitic bipolar transistor remains inoperative.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1a illustrates a prior art vertical MOSFET.

Fig. 1b is a schematic diagram illustrating an equivalent circuit for the MOSFET of Fig. 1a.

Fig. 2 is a graph showing representative gate charge characteristics of a MOSFET.

Fig. 3 illustrates a first prior art MOSFET having reduced gate-drain capacitance.

Fig. 4 illustrates a second prior art MOSFET having reduced gate-drain capacitance.

Fig. 5 illustrates an embodiment of the invention wherein a MOSFET for very high frequency (VHF) operation is made to have a relatively low C_{GD}.

Figs. 6-12 illustrate various process steps used in one embodiment of a method for forming the VHF MOSFET of Fig. 5.

Fig. 13 illustrates an alternative embodiment of a MOSFET capable of ultra high frequency (UHF) operation having a low C_{GD} in accordance with the present invention where upper and lower gates are formed.

Fig. 14 illustrates the MOSFET of Fig. 13 with an upper gate coupled to source voltage.

Fig. 15 illustrates an alternative embodiment of a MOSFET having a low C_{GD} in accordance with the present invention where an upper gate is removed.

Fig. 16a illustrates an alternative embodiment of a MOSFET capable of UHF to super high frequency (SHF) operation having a very low C_{GD} in accordance with the present invention where a lower gate and an upper gate terminate over a portion of the channel region.

Fig. 16b illustrates with dashed lines the improved gate charge characteristics of the MOSFET of Fig. 16a.

Figs. 17 and 18 illustrate process steps used to form the MOSFET of Fig. 16.

Fig. 19 illustrates an alternative embodiment of a MOSFET having a very low C_{GD} in accordance with the present invention which utilizes an overhanging upper gate to eliminate etching of a vertical portion of the gate.

Fig. 20 illustrates a process step used to form the MOSFET of Fig. 19.

Fig. 21 illustrates an alternative embodiment of a MOSFET having a low C_{GD} in accordance with the present

invention which utilizes a split upper gate.

Fig. 22 illustrates an alternative embodiment of a MOSFET having a low C_{GD} in accordance with the present invention which utilizes separate gates overlying an oxide layer of a single thickness.

Fig. 23 shows a schematic representation of a MOSFET having an upper gate and a lower gate.

Fig. 24 illustrates an embodiment of a lateral MOSFET having a low C_{GD} in accordance with the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Fig. 5 shows an embodiment of the invention capable of VHF operation, where conductive gate 80, formed of either Al, Al containing Si, or Al containing Cu and Si, or any other compatible gate material, is formed over drain 82 with a first thickness of oxide 86 therebetween. In one embodiment, oxide 86 is 10,000 Å thick. Gate 80 is also formed over P body regions 88 with a second thickness of oxide 90 therebetween. In one embodiment, oxide 90 is 900 Å thick. Also shown in Fig. 5 is N+ source region 92 and P+ body contact region 94, with conductive source contact 96 shorting together N+ source region 92 and P+ body contact region 94. N+ drain contact 95 is shown contacting a bottom surface of drain 82.

Since oxide layer 86 is significantly thicker than oxide layer 90, the capacitance between gate 80 and drain 82 will be relatively low due to this increased dielectric thickness, while the capacitance between gate 80 and source region 92 will not significantly change. The thickness of gate oxide layer 90 is dictated by design considerations to provide a desired threshold voltage V_T and dielectric breakdown voltage.

Lateral dimensions of the various above-described regions for one embodiment of the invention are shown in Fig. 5.

Thus, in the embodiment of Fig. 5, a gate-to-

source voltage V_{GS} will cause the field created between gate 80 and N+ source region 92 and between gate 80 and P- body region 88 to invert the channel region within P- body region 88, causing an ohmic channel to be created between N+ source region 92 and N- drain 82. This inversion of P- body region 88 is primarily due to the field created by the portion of gate 80 located above thin oxide layer 90. The portion of gate 80 overlying thick oxide layer 86 has a reduced effect on the conductance of the MOSFET and provides shielding over drain 82.

Figs. 6-12 illustrate a method to form the structure of Fig. 5.

In Fig. 6, an epitaxial layer 98 of N-type conductivity, having an impurity concentration of approximately 3 x 10E15 atoms/cm^3 to achieve a breakdown voltage of between 80 to 100 V is deposited on an N+ substrate and has formed over it silicon dioxide layer 100 having a thickness of preferably 10,000 Å.

Oxide layer 100 would be formed to have a thickness of 7,000 Å for embodiments using two metal layers (a gate layer and a source layer). This two metal layer embodiment is illustrated on the right hand side of Fig. 5.

Oxide layer 100 may be formed by wet oxidation at approximately 1,000°C for 3-5 hours. Over oxide layer 100 is then formed silicon nitride layer 102 by a chemical vapor deposition (CVD) process at approximately 790°C to achieve a thickness of approximately 1,000 Å.

In Fig. 7, oxide layer 100 and silicon nitride layer 102 are etched by using a conventional positive photoresist, contact masking technique and an anisotropic etch to expose portion 104 of substrate 98. In a preferred embodiment, a Lam™ dry etcher is used. The exposed portion 104 of substrate 98 is to coincide with the desired location of the body-source diffusion.

In Fig. 8, boron is implanted into substrate 98 through exposed portion 104 and diffused to form P body

region 106. In the preferred embodiment, boron ions are implanted at an energy of 70KeV with a dosage of 6 x 10E13/cm^2. The exposed silicon is then oxidized for 30 minutes at 900°C in a dry O_2 atmosphere to form oxide layer 107 in order to prevent damage to the substrate during a subsequent diffusing process conducted in an N_2 atmosphere. The implanted ions are diffused by a ramp up and dwell diffusing process, where the temperature of the wafer is ramped from 900°C to 1,100°C at a rate of approximately 8°C/minute and held for approximately 2.5 hours and then ramped down to 900°C for one hour (including ramping time) in an N_2 atmosphere, to form P body region 106 having a depth of approximately two microns. The required characteristics of P body region 106 will depend on the desired breakdown voltage of the device and will be readily apparent to one of ordinary skill in the art.

In Fig. 9, an additional boron implant is conducted to form P+ contact region 108 within P body region 106. In the preferred embodiment, boron ions are implanted at an energy of approximately 100KeV with a dosage of 10E15 to 10E16/cm^2. The implant energy is calculated to form P+ region 108 at a depth below the surface of substrate 98 where it is desired to have P+ region 108 interface with a subsequently formed source region. Next, the wafer is dipped in a 10:1, H_2O:HF solution for approximately 45 seconds to remove oxide layer 107, and arsenic is implanted to form N+ source region 110 at the surface of substrate 98. In the preferred embodiment, arsenic ions are implanted at an energy of approximately 40KeV with a dosage of 10E16/cm^2.

In Fig. 10, silicon dioxide layer 112 is deposited at 400°C over the surface of the wafer to a thickness of approximately 500 Å to prevent any out-diffusing of arsenic ions forming source region 110. The impurities within N+ source region 110 and P+ body contact region 108 are then driven-in for approximately 30 minutes

at approximately 1,000°C so that N+ source region 110 extends approximately 0.3 microns beneath the surface of substrate 98. During this drive-in period, P+ body contact region 108 and P body region 106 also diffuse.

In Fig. 11, an oxide etchant is used to remove oxide layer 112 and a portion of oxide layer 100 so as to leave overhanging silicon nitride portion 114. In the preferred embodiment to conduct this etching, the wafer is immersed in any oxide etch solution with a known and controlled etch rate. For example, six parts H_2O to one part ammonium fluoride may be used at 25°C for a period calculated to create the desired overhanging of nitride portion 114 relative to P body 106. For the diffusion process previously described, a 1.4 micron overhang of nitride portion 114 is satisfactory.

In Fig. 12, the wafer is immersed in hot phosphoric acid (or an equivalent thereof) at a temperature of approximately 160°C for one hour to remove silicon nitride portion 114 and the remainder of silicon nitride layer 102 over oxide layer 100. As a precaution against arsenic outgassing, the wafer is gradually ramped up to a temperature of 920° in a tube furnace for approximately 15 minutes in a dry O_2 atmosphere to form a thin layer of oxide 50-100 Å thick. Silicon dioxide layer 116 is then grown over the surface of the wafer at approximately 920°C for approximately 25 minutes in an atmosphere of wet O_2 to a thickness of 2500-3000 Å over N+ source region 110. An increased thickness of oxide layer 116 is inherently formed over N+ source region 110. The portion of oxide layer 116 over P body region 106, forming the gate oxide, will be approximately 900 Å at this stage.

Next, as shown in Fig. 5, a portion of oxide layer 116 over source region 110 is etched to expose a portion of source region 110. In an alternative embodiment, an additional etch is conducted to etch source region 110 through to expose P+ body contact region 108. A conductive metal layer is then formed over the surface

of the wafer by the deposition of either Al, Al containing Si, Al containing Cu and Si, or any other conventional metal layer to a thickness of approximately one micron. In the VHF embodiment of the invention, aluminum, copper, and silicon are sputtered over the surface of the wafer. A metal layer containing Si is preferred to minimize migration of the metal atoms into the silicon substrate. For higher frequency embodiments, metal source contact 96 preferably comprises a WTi barrier layer in contact with the source region overlaid by approximately 1 micron of Au.

The resulting metal layer is then masked and etched to form source contact 96 and gate 80 as shown in Fig. 5. Source contact 96 contacts N+ source region 92 and also contacts P+ contact region 94 through N+ source region 92, due to source region 92 and P+ contact region 94 being so highly doped as to be in ohmic contact with each other. Ohmic contact is further enhanced by implant damage to the crystalline substrate.

In an alternative embodiment, source region 92 is anisotropically etched completely through in the contact area so that source contact 96 directly contacts both P+ body contact region 94 and N+ source region 92.

Any embodiment herein may be formed with a tungsten (W) or refractory metal silicide layer deposited prior to the formation of source contact 96 to prevent migration of atoms and/or to reduce contact resistance.

In practice, it is desirable to form source contact 96 close to the channel region to minimize on-resistance.

The method described in Figs. 6-12 and Fig. 5 forms a MOSFET having a low gate-drain capacitance C_{GD}, wherein source region 92, body contact region 94, and body region 88 are formed self-aligned with the drain edge portion of gate 80. In this method to form a VHF MOSFET, there are no critical alignment tolerances, which makes this above described process one that will inherently

result in a high yield of MOSFETs on a wafer.

In the structure of Fig. 5, the portion of gate 80 formed over thick oxide portion 86 is connected to the portion of gate 80 formed over thin oxide portion 90 by a vertical gate portion. In an alternative embodiment of the MOSFET structure of Fig. 5, the metal layer is formed by a method which will intentionally provide poor step coverage, such as by an evaporation process, so that the vertical portion of gate 80 will be relatively thin compared to the horizontal portions of gate 80. Such a resulting structure, having relatively thin vertical portions of gate 80 is then isotropically etched using a commercially available wet aluminum etch containing phosphoric acid, assuming gate 80 is composed of Al, so as to isolate the portion of gate 80 formed above thick oxide portion 86 from the portion of gate 80 formed above thin oxide portion 90. This embodiment is shown in Fig. 13, where upper gate 120 and lower gates 124 result. The remaining elements in the MOSFET of Fig. 13 are similar to those in Fig. 5 and are formed using a process similar to that described with respect to Fig. 5.

In all the embodiments described herein, for higher frequency operation, the source contact is preferably an overlay metal (such as shown on the right hand side of Fig. 5). This allows P body region 88 to be relatively narrow (~10 microns) for low drain-to-source capacitance C_{DS}. The various figures do not incorporate a two metal layer for simplicity.

In the MOSFET structure of Fig. 13, gate voltage is applied to lower gates 124, while a separate voltage is applied to upper gate 120. A positive voltage applied to upper gate 120 will make upper gate 120 effective in creating additional carriers in the N- drain 82 and increasing the current handling capability of the MOSFET. A negative voltage on upper gate 120 will increase the breakdown voltage of the MOSFET.

In Fig. 14, a structure identical to Fig. 13 is

shown except that upper gate 120 is connected to the source voltage instead of to an upper gate voltage. Thus, in this configuration, upper gate 120 acts as a field plate for increasing the depletion region in drain 82 when the MOSFET is in its off state. This serves to enhance the breakdown voltage of the MOSFET.

In an alternative embodiment, shown in Fig. 15, upper metal gate 120 of Fig. 13 is removed using a wet etch process. As shown in Fig. 15, mask 125, shown in dashed outline, is first formed to expose a center portion of the gate metal over oxide 86. The wet etch process removes the exposed metal and also removes the gate metal adjacent the exposed portion. Gate voltage is applied to gates 124 to invert the channel regions in P body regions 88.

In the highest speed embodiment of the invention, shown in Fig. 16a, lower gate 140 is formed so as to only overlap a portion of the channel region in P body region 88, while upper gate 144 overlaps the remaining portion of the channel region in P body region 88. This configuration further reduces the C_{GD} of the MOSFET, since lower gate 140 is relatively physically distant from drain 82. In this configuration, the field generated by upper gate 144 in conjunction with the field created by lower gate 140 is used to invert the channel region in P body region 88 to form an ohmic channel between N+ source region 92 and N- drain 82.

The structure of Fig. 16a is formed using a method similar to that described with respect to Fig. 5, except that after drive-in of N+ source region 92 and P+ contact region 94, the oxide etch, previously discussed with respect to Fig. 11, is conducted for less time so as to etch away less of oxide layer 100 under silicon nitride layer 102. This is shown in Fig. 17. The terminating portion of oxide layer 100 is located above an exposed portion of P body region 88 where it is desired for lower gate 140 and upper gate 144 to interface. Lateral

dimensions of one embodiment are shown in Fig. 17.

In the step illustrated in Fig. 18, silicon nitride layer 102 is removed, and oxide layer 116 is grown.

As shown in Fig. 16a, oxide 116 is etched, and source region 92 and body contact region 94 are optionally etched in order to short these regions together by a metal source contact. A metal conductive layer is then deposited, preferably by evaporation, so as to provide a metal layer having poor step coverage. This metal layer is then masked and isotropically etched so as to form upper gate 144, lower gate 140, and, optionally, source contact 148. Source contact 148 may also be formed later through an opening in a subsequently deposited oxide layer and oxide portion 116, resulting in a two layer metal embodiment, preferable for high frequency and high density devices.

In the structure of Fig. 16a, C_{GD} has been virtually eliminated. Upper gate 144 may be connected to source region 92 through an alternating current (AC) short circuit, and the resulting drain-to-upper gate capacitance, which constitutes C_{GD} (or C_{rss}) in the prior art MOSFETs of Figs. 1, 3 and 4, now appears in this invention as a part of C_{DS}. The dramatically improved switching characteristics of the new structure are shown by the broken lines in Fig. 16a superimposed on the gate charge characteristics graph of Fig. 2.

Fig. 19 illustrates another embodiment of the invention which is a variation of the structure of Fig. 16a. In Fig. 19, upper gate 144 overhangs oxide portion 86. This structure has the advantage in that the channel region between N+ source 92 and drain 82 is completely overlapped by the combination of upper gate 144 and lower gate 140 so as to insure the inversion of the channel region. Further, the structure may be formed without any requirement for an isotropic etch to etch away a vertical portion of the metal layer initially connecting

upper gate 144 to lower gate 140.

The method for forming the structure of Fig. 19 is similar to that for forming the structure of Fig. 5, except, in the process steps illustrated in Figs. 11 and 12 for forming the MOSFET of Fig. 5, nitride layer 102 is partially etched to 40-50% of its original thickness. This completely removes overhanging nitride portion 114. The sidewalls of oxide portion 100, shown in Fig. 20, is then re-etched 1,000-2,000 Å to create a new small overhanging nitride portion 114A. A metal layer is then deposited by, for example, evaporation, and a vertical portion is not formed on a sidewall of oxide layer 100. The resulting structure is masked and etched to form the structure of Fig. 19.

Fig. 21 shows a higher frequency embodiment of the invention which is a variation of the MOSFETs having a separate upper gate. In Fig. 21 upper gates 160 and 162 are shown separated by a gap. This structure results in a lower drain-to-upper gate capacitance C_{GD} due to less upper gate area over drain 82. High current capability is retained by the field created by upper gates 160 and 162. This split upper gate configuration may be used in any of the above-described embodiments including Fig. 5, where gate 80 overlying oxide 86 may be opened up to further reduce C_{GD}.

In the high frequency MOSFET of Fig. 21, source contact 96 is preferably comprised of a 2,000 Å WTi barrier layer under a 9,000 Å Au layer in an overlay (two layer metal) configuration. In an embodiment wherein a metal source contact is to directly contact both the P+ body contact region and the N+ source region, as shown in Fig. 19, platinum silicide is preferably used as a contact layer under the WTi to improve ohmic contact.

In one embodiment of the MOSFET of Fig. 21, the starting material is an N+ (antimony) <1-0-0> silicon substrate with an 8 micron epitaxial layer formed therein having a resistivity of 1.5 Ωcm.

Oxide layer 86 has a thickness of 7,000 Å. Gate oxide 90 has a thickness of 800 Å. The body opening mask through which body region 88 impurities are implanted is 8.5 microns wide. The space between gates 124 is approximately 25 microns. The source contact mask opening is 2 microns. The gate 124, 160, 162 length is approximately 2.5 microns.

The implant doses are as follows:

For P body region 88: 5 x 10E13/cm^2 at 70KeV using boron ions;

For P+ body contact region 94: 1 x 10E15/cm^2 at 100 KeV using boron ions; and,

For source region 92: 1 x 10E16/cm^2 at 40KeV using arsenic ions.

The channel length is approximately 1 micron, and the channel width is approximately 1100 microns.

The resulting structure has the following electrical properties:

V_{TH} @ 25μA: 1.0-1.5V

BV_{DSS} @ 250μA: 80V

gm @ 25mA, V_D = 10V: 0.025 mhos

RD_{ON} @ V_G = 10V: 32 ohms

At V_G = 0V, V_D = 28V:

C_{iss} ~ 1.25 pf (C_{GS} + C_{GD})

C_{rss} ~ 0.0425 pf (C_{GD})

C_{Oss} ~ 0.625 pf (C_{DS} + C_{GD})

When overlay metal is used, a Faraday shield is preferably connected to the source contact and placed between the gate bonding pad and the drain to prevent pad capacitance from becoming part of C_{GD}.

In additional embodiments, the upper gate described with respect to Figs. 13, 14, 16a, 19, and 21 is deposited on the same thickness of oxide as the lower gate and separated from the lower gate by a masking and etch process. A representative embodiment is shown in Fig. 22, where gates 152 and 154 are formed over a same thickness

of oxide 156. Further, both gates 152 and 154 may or may not overlie a portion of the channel region. The remaining elements in Fig. 22 are identical to those shown in Fig. 5.

Fig. 23 shows a new schematic representation of the resulting structures described herein which utilize a separate upper gate and lower gate.

Fig. 24 shows a lateral MOSFET in accordance with another embodiment of the invention, where gate portion 160 is formed over thick oxide 86, and gate portion 162 is formed over thin oxide 90. Gate portions 160 and 162 may be separated as described with respect to Fig. 13. The MOSFET of Fig. 24 is formed using steps similar to those used to form the vertical MOSFET of Fig. 5, except, in Fig. 23, N+ drain contact region 168 is formed in a top surface of substrate 82. Substrate 82 may be of an N or P type. If substrate 82 is of a P type, P body region 88 may be deleted.

Thus, an improved MOSFET has been described which exhibits a lower gate-to-drain capacitance C_{GD}, wherein source and body regions are precisely aligned with respect to a gate without the use of any critical masking steps, and wherein a parasitic bipolar transistor has been rendered inoperative. While particular embodiments of the present invention have been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from this invention in its broader aspects. For example, all conductivity types may be made opposite to those specifically mentioned, and the various dimensions may be modified as necessary. Accordingly, the appended claims are to encompass within their scope all such changes and modifications that fall within the true spirit and scope of this invention.

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CLAIMS

What is claimed is:

1. A MOSFET structure comprising:

a substrate of a first conductivity type having a top surface;

a drain of said first conductivity type;

a body region of a second conductivity type formed in said top surface of said substrate;

a source region of said first conductivity type formed in said top surface of said substrate and formed within said body region;

a conductive gate having an upper portion and a lower portion, said lower portion being insulated from a channel region within said body region located between said source region and said drain by an insulation layer of a first thickness, said upper portion being insulated from said drain by an insulation layer of a second thickness, wherein said second thickness is greater than said first thickness.

2. The MOSFET structure of Claim 1 wherein said drain includes a drain contact region of a first conductivity type formed in said top surface of said substrate.

3. The MOSFET structure of Claim 1 wherein said drain includes a drain contact portion of said substrate formed on a bottom surface of said substrate.

4. The MOSFET structure of Claim 1 wherein said upper portion and said lower portion of said gate are connected by a vertical gate portion.

5. The MOSFET structure of Claim 1 wherein said upper portion and said lower portion of said gate are

not connected by a vertical gate portion.

6. The MOSFET structure of Claim 5 wherein said lower portion of said gate overlaps a first portion of said channel region and said upper portion of said gate overlaps a second portion of said channel region.

7. The MOSFET structure of Claim 5 wherein said upper portion of said gate overhangs said insulation layer of said second thickness.

8. The MOSFET structure of Claim 1 further comprising a body contact region of said second conductivity type formed within said body region for being electrically shorted to said source region.

9. A MOSFET structure comprising:

a substrate of a first conductivity type having a top surface;

a drain of said first conductivity type;

a body region of a second conductivity type formed in said top surface of said substrate;

a source region of said first conductivity type formed in said top surface of said substrate and formed within said body region;

a conductive gate having a first portion separated from a second portion, said first portion being insulated from a channel region within said body region located between said source region and said drain by a first insulation layer portion, said second portion being insulated from said drain by a second insulation layer portion, wherein said first and second insulation layer portions have identical thicknesses.

10. The MOSFET structure of Claim 9 wherein said first portion and said second portion each overlie a

portion of said channel region.

11. The MOSFET structure of Claim 9 wherein said drain includes a drain contact region of a first conductivity type formed in said top surface of said substrate.

12. The MOSFET structure of Claim 9 wherein said drain includes a drain contact portion of said substrate formed on a bottom surface of said substrate.

13. A MOSFET structure pair comprising:

a substrate of a first conductivity type having a first surface, a bottom surface of said substrate acting as a drain contact region for said MOSFET structure;

a first and second body region of a second conductivity type formed in said top surface of said substrate and separated from one another by a first area of said top surface of said substrate;

first and second source regions of said first conductivity type formed in said top surface of said substrate and within respective ones of said body regions;

a conductive gate having an upper portion and a lower portion, said lower portion being insulated from a channel region within said first body region between said first source region and a terminal portion of said first area by an insulation layer of a first thickness, said second lower portion being insulated from a channel region within said second body region between said second source region and a terminal portion of said first area by an insulation layer of said first thickness, said upper portion being insulated from said first area of said top surface of said substrate by an insulation layer of a second thickness, wherein said second thickness is

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greater than said first thickness.

14. The MOSFET pair structure of Claim 13 wherein said upper portion and lower portion of said gate are connected by vertical gate portions.

15. The MOSFET pair structure of Claim 13 wherein said upper portion and said lower portion of said gate are not connected by vertical gate portions.

16. The MOSFET pair structure of Claim 15 wherein said upper portion of said gate is split into a first upper portion and a second upper portion, wherein neither said first upper portion nor said second upper portion overlies a central portion of said first area.

17. A MOSFET structure comprising:

a substrate of a first conductivity type having a top surface;

a drain of a second conductivity type formed in said top surface of said substrate;

a source region of said second conductivity type formed in said top surface of said substrate;

a conductive gate having a first portion separated from a second portion, said first portion being insulated from a channel region between said source region and said drain by a first insulation layer portion, said second portion being insulated from said channel region by a second insulation layer portion.

18. The MOSFET structure of Claim 17, wherein said first and second insulation layer portions have identical thicknesses.

19. A method of forming a MOSFET structure with a source region and a body region self-aligned with a

gate, said method comprising the steps of:

forming a first layer of insulation over a top surface of a substrate, said substrate being of a first conductivity type and acting as a drain;

removing a portion of said insulation layer to expose a portion of said top surface of said substrate;

introducing impurities of a second conductivity type into said exposed portion of said substrate;

introducing impurities of said first conductivity type into said exposed portion of said substrate;

diffusing said introduced impurities to form a body region of said second conductivity type and a source region of said first conductivity type formed within said body region;

removing portions of said insulation layer to expose said body region after diffusion of said impurities of said second conductivity type;

forming a first insulation layer portion over a channel region in said exposed portions of said body region while forming a second insulation layer portion over said drain adjacent to said channel region;

depositing a conductive gate layer over said first insulation layer portion and said second insulation portion.

20. The method of Claim 19 wherein said second insulation layer portion is thicker than said first insulation layer portion.

21. The method of Claim 19 wherein said second insulation layer portion is of the same thickness as said first insulation layer portion.

22. The method of Claim 19 further comprising

the step of depositing a layer of silicon nitride over said first insulation layer after said step of depositing said first insulation layer.

23. The method of Claim 19 further comprising the step of etching vertical portions of said gate layer to isolate an upper portion of said gate from a lower portion of said gate.

24. The method of Claim 23 wherein said lower portion and said upper portion of said gate both overlie a portion of said channel region within said body region.

25. The method of Claim 24 wherein said upper portion of said gate overhangs said second insulation layer portion over a portion of said channel region of said body region.

26. The method of Claim 23 wherein a central portion of said upper gate portion of said gate is removed.



AMENDED CLAIMS

[received by the International Bureau
on 1 July 1991 (01.07.91);
original claims 1-9,13-15,17;18 and 24 cancelled;
claims 10-12, 16 and 19 amended and renumbered as
claims 1-3, 4 and 5; claims 20-23 and 25 renumbered
as claims 6-9 and 10; claim 26 amended and renumbered
as claim 11; new claims 12-22 added (7 pages)]

What is claimed is:

1. A MOSFET structure comprising:

a substrate of a first conductivity type having a top surface;

a drain of said first conductivity type being more highly doped than said substrate;

a body region of a second conductivity type formed in said top surface of said substrate;

a source region of said first conductivity type formed in said top surface of said substrate and formed within said body region;

a conductive gate having a first portion separated from a second portion, said first portion being insulated from a channel region within said body region located between said source region and a periphery of said body region by a first insulation layer portion, said second portion being insulated from said top surface of said substrate by a second insulation layer portion, wherein said first and second insulation layer portions have substantially identical thicknesses,

wherein said first portion and said second portion each overlie a portion of said channel region within said body region.

2. The MOSFET structure of Claim 1 wherein said drain is formed in said top surface of said substrate.

3. The MOSFET structure of Claim 1 wherein said drain is formed on a bottom surface of said substrate.

4. A MOSFET pair structure comprising:

a substrate of a first conductivity type having a first surface, a bottom surface of said substrate acting as a drain contact region for said MOSFET pair structure;

a first and second body region of a second conductivity type formed in said top surface of said substrate and separated from one another by a first area of said top surface of said substrate;

first and second source regions of said first conductivity type formed in said top surface of said substrate and within respective ones of said body regions;

a conductive gate having an upper portion, a first lower portion, and a second lower portion, said first lower portion being insulated from a channel region within said first body region between said first source region and a periphery of said first body region by an insulation layer of a first thickness, said second lower portion being insulated from a channel region within said second body region between said second source region and a periphery of said second body region by an insulation layer of said first thickness, said upper portion being insulated from said first area of said top surface of said substrate by an insulation layer of a second thickness, wherein said second thickness is greater than said first thickness,

wherein said upper portion of said gate is split into a first upper portion and a second upper portion, wherein neither said first upper portion nor said second upper portion overlies a central portion of said first area.

5. A method of forming a MOSFET structure with a source region and a body region self-aligned with a gate, said method comprising the steps of:

forming a first layer of insulation over a top surface of a substrate, said substrate being of a first conductivity type and acting as a drain;

removing a portion of said insulation layer to expose a portion of said top surface of said substrate;

introducing impurities of a second conductivity type into said exposed portion of said substrate;

introducing impurities of said first conductivity type into said exposed portion of said substrate;

diffusing said introduced impurities to form a body region of said second conductivity type and a source region of said first conductivity type formed within said body region;

removing portions of said insulation layer to expose said body region after diffusion of said impurities of said second conductivity type;

forming a first insulation layer portion over a channel region in said exposed portions of said body region while forming a second insulation layer portion over said drain adjacent to said channel region;

depositing a conductive gate layer over said first insulation layer portion and said second insulation portion; and

etching said conductive gate layer to separate said gate layer into first and second portions, wherein said first and second portions each overlie a portion of said channel region within said body region.

6. The method of Claim 5 wherein said second insulation layer portion is thicker than said first insulation layer portion.

7. The method of Claim 5 wherein said second insulation layer portion is of the same thickness as said first insulation layer portion.

8. The method Claim 5 further comprising the step of depositing a layer of silicon nitride over said first insulation layer after said step of depositing said first insulation layer.

9. The method of Claim 5 wherein the step of etching comprises etching vertical portions of said gate layer to isolate an upper portion of said gate from a lower portion of said gate.

10. The method of Claim 9 wherein said upper portion of said gate overhangs said second insulation layer portion over a portion os said channel region of said body region.

11. A method of forming a MOSFET structure with a source region and a body region self-aligned with a gate, said method comprising the steps of:

forming a first layer of insulation over a top surface of a substrate, said substrate being of a first conductivity type and acting as a drain;

removing a portion of said insulation layer to expose a portion of said top surface of said substrate;

introducing impurities of a second conductivity type into said exposed portion of said substrate;

introducing impurities of said first conductivity type into said exposed portion of said substrate;

diffusing said introduced impurities to form a body region of said second conductivity type and a source region of said first conductivity type formed within said body region;

removing portions of said insulation layer to expose said body region after diffusion of said impurities of said second conductivity type;

forming a first insulation layer portion over a channel region in said exposed portions of said body region while forming a second insulation layer portion over said drain adjacent to said channel region;

depositing a conductive gate layer over said first insulation layer portion and said second insulation portion,

wherein a central portion of said upper gate portion of said gate is removed.

12. A MOSFET structure comprising:

a substrate of a first conductivity type having a top surface;

a drain of said first conductivity type being more highly doped than said substrate;

a body region of a second conductivity type formed in said top surface of said substrate;

a source region of said first conductivity type formed in said top surface of said substrate and formed within said body region;

a conductive gate having an upper gate portion electrically separated from a lower gate portion, said lower gate portion overlapping and being insulated from a first portion of a channel region within said body region located between said source region and a periphery of said body region by an insulation layer of a first thickness, said upper gate portion overlapping and being insulated from a second portion of said channel region by an insulation layer of a second thickness, said upper gate portion also extending over said top surface of said substrate of said first conductivity type, wherein said second thickness is greater than said first thickness.

13. The MOSFET structure of Claim 12 wherein said upper gate portion is connected to receive an upper gate voltage for inverting said second portion of said channel region, and said lower gate portion is connected to receive a separate lower gate voltage for inverting said first portion of said channel region.

14. The MOSFET structure of Claim 12 wherein said upper gate portion is connected to said source region through an AC short circuit.

15. The MOSFET structure of Claim 12 wherein said upper gate portion overhangs said insulation layer of said second thickness.

16. A MOSFET structure comprising:

a substrate of a first conductivity type having a top surface;

a drain of said first conductivity type being more highly doped than said substrate;

a body region of a second conductivity type formed in said top surface of said substrate;

a body contact region of said second conductivity type formed within said body region and being more highly doped than said body region;

a source region of said first conductivity type, being more heavily doped than said substrate, formed within said body region so as to completely overlie said body contact region; and

a conductive gate insulated from and formed over a channel region within said body region located between said source region and a periphery of said body region.

17. The MOSFET structure of Claim 16 further comprising a conductive electrode directly contacting said source region and not directly contacting said body

contact region, whereby electrical contact with said body contact region is made through said source region, doping of said source region and said body contact region being of such a level as to cause said source region and said body contact to be essentially in ohmic contact with each other.

18. The MOSFET structure of Claim 16 further comprising a conductive electrode penetrating said source region so as to be in direct contact with source region and said body contact region, thereby shorting said source region to said body contact region.

19. The MOSFET structure of Claim 16 wherein said drain is formed in said top surface of said substrate.

20. The MOSFET structure of Claim 16 wherein said drain is formed on a bottom surface of said substrate.

21. The MOSFET structure of Claim 4 wherein said upper portion is shorted to said first and second lower portions.

22. The MOSFET structure of Claim 4 wherein said upper portion is not shorted to said first and second lower portions.