

PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Field Effect Transistor

We, RADIO CORPORATION OF AMERICA, a Corporation organized under the laws of the State of Delaware, United States of America, of 30, Rockefeller Plaza, City and State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to improved field effect transistors of the type having an insulated offset gate.

An insulated gate field effect transistor comprises a channel of semiconductor material and two spaced connections to the channel which are referred to as the source and the drain. As used herein, the source is the connection from which majority carriers flow into the channel. A field effect transistor includes also a gate opposite and spaced from the channel by insulator material. In a planar type of field effect transistor, the channel, the source, and the drain are constructed along a common plane or surface.

The operating characteristics of a planar type field effect transistor for use at higher frequencies may be improved by offsetting the gate toward the source and away from the drain. In their geometry, there is a portion of the channel adjacent the drain which is not opposite the gate, although insulator material may extend opposite this portion of the channel. It has been found that the characteristics of such a device may vary with time and changes in ambient temperature. This variation in characteristics is believed to be due to movements of ions and in variation in the concentrations of these ions on or in the surface of the insulator over the channel portion which is not covered by the offset gate.

An object of this invention is to provide

a new and improved insulated gate field effect transistor.

In general, the invention includes a field effect transistor having a channel, a source and a drain connected to the channel, and a gate spaced from the channel by insulating material. The insulator material extends over the entire area between the source and the drain, and is thicker opposite the portion of the channel adjacent the drain and is thinner opposite the portion of the channel adjacent the source. The gate electrode extends over the thinner portion of insulator material.

In the accompanying drawings:

FIGURE 1 is a partially sectional perspective view of a first embodiment of the invention;

FIGURE 2 is a sectional view of a second embodiment of the invention; and

FIGURE 3 is a sectional view of a third embodiment of the invention.

Similar reference numerals are used for similar structures throughout the drawings.

FIGURE 1 illustrates an embodiment 21 of the invention having an insulator with a stepped thickness in the direction of current flow through the channel. The device 21 includes a semiconductor body 23 of resistive P-type silicon, a source 25 and a drain 27, both of conducting N-type silicon in spaced locations in the body 23. An insulator 29 overlies the region of the body 23 between the source 25 and the drain 27. This region is referred to as the channel 31.

The channel 31 is considered to be N-type because the drain currents through the channel are electron currents. The channel 31 may have an excess of electrons when no voltage is applied to the gate, or an excess of electrons may be induced in the channel 31 by applying a positive voltage to the gate. The insulator 29 is preferably of silicon oxide, although other insulators may be used,

[Price 4s. 6d.]

The insulator 29 has two different thicknesses of steps 29a and 29b. The insulator 29 is thinner (portion 29a) over the portion of the channel 31 adjacent the source 25 and is thicker (portion 29b) over the part of channel 31 adjacent the drain 27. This thicker portion provides an improved operational stability in all of the embodiments of the invention.

A gate 33, preferably of metal, rests on the insulator 29 which spaces the gate 33 from the channel 31. The gate 33 may extend only over the thinner portion 29a of the insulator 29. It is preferred, as shown in FIGURE 1, that the gate 33 extend over the thinner and thicker portions 29a and 29b of the insulator 29.

A low resistance source electrode 35 of metal contacts the source 25 and a low resistance drain electrode 37 of metal contacts the drain 27. A layer 30 of insulator material extends over the surface of the body 23 adjacent the source, drain, and gate electrodes. The layer 30 is passive and plays no active part in the operation of the device.

The first embodiment 21 may be operated with a circuit 29 which comprises a source conductor 41 connecting the source electrode 25 to ground 43; a gate section comprising a gate conductor 45 connecting the gate electrode 33 to ground 43 through a gate voltage supply 47 and a signal source 49 connected in series; and a drain section comprising a drain conductor 51 connecting the drain electrode 37 to ground 43 through a drain-to-source voltage supply 53 and a load resistor 55 connected in series.

The voltage applied to the gate 33 acts principally through the gate portion over the thinner insulator portion 29a and modifies the current passing from the source 25 to drain 27. The gate portion over the thicker insulator portion 29b acts principally as a biased electrostatic shield for further stabilizing the operation of the device.

The output signal of the device may be taken across the load resistor 55 at end terminals 57. An amplified replica of the signal applied to the gate 33 from the source 49 appears across the terminals 57. The polarity of the bias and source shown in FIGURE 1 are for operating a device 21 having an N-type channel.

FIGURE 2 illustrates a second embodiment of the invention 61 similar to the embodiment 21 illustrated in FIGURE 1 except that the gate electrode 33 extends only over the thinner portion 29a of the insulator 29, and a separate electrode 63 extends over the thicker portion 29b of the insulator 29. As shown, the electrode 63 is connected with a conductor 65.

The second embodiment 61 may be operated in the circuit 39 illustrated in FIGURE 1 with the electrode 63 and the conductor 65 floating. Optionally, the conductor 65 may

be directly connected with the conductor 45 so that both the gate electrode 33 and the electrode 63 are at the same voltage.

By another alternative, the second embodiment 61 may be operated in the circuit 39 illustrated in FIGURE 1, but with the electrode 63 biased more or less negative with respect to gate electrode 33 (by means not shown) through the conductor 65.

FIGURE 3 illustrates a third embodiment 71 of the invention similar to the first embodiment 21 illustrated in FIGURE 1, except that the gate electrode 33 extends only over the thinner portion 29a of the insulator 29, and the thicker portion 29b of the insulator 29 is not covered. The third embodiment 71 may be operated in the circuit 39 illustrated in FIGURE 1.

The improved operational stability of the device of the invention is achieved by providing in the devices an offset gate and a thicker insulator over the channel portion adjacent the drain as shown in FIGURE 3. The operational stability of the device is further improved by providing an electrostatic shield in the form of an electrode 63 as shown in FIGURE 2. This stabilization may be modified by applying a voltage to the conductor 65 as described above with respect to FIGURE 2. In the embodiment shown in FIGURE 1, the thicker insulator is covered with the gate electrode which is a biased shield.

The circuit 39 illustrated in FIGURE 1 is illustrative of circuits generally that are useful. Other circuits may be used to operate one or more embodiments of the invention. For example, the circuit may be an amplifier circuit in a radio frequency receiver. Further, the signal and voltage sources 49 and 47 each may provide a signal: d.c., low frequency a.c., or high frequency a.c. When so operated, the device and circuit illustrated in FIGURE 1 may function also as a mixer.

As shown in FIGURE 1, the body 23 is floating (not connected to the circuit). Although not shown, the body 23 may also be biased, either with a d.c. or with an a.c. signal to provide an auxiliary signal input to the device. Also, if the body 23 is thin and relatively resistive, an auxiliary gate electrode (not shown) may be positioned adjacent the body 23 opposite the gate 33 to provide an auxiliary signal input.

Embodiments of the invention may include structures having channels constituted of a single crystal, such as silicon produced directly in a single crystal body, or produced epitaxially on a single crystal body. For such single crystal structures, the insulator may be deposited as from a vapor phase or, in some materials such as silicon, may be grown in situ as by thermal oxidation.

The embodiments of the invention may include also structures having a channel of

polycrystalline material, such as cadmium sulfide, cadmium selenide, or tellurium, preferably produced as deposition from a vapor. For such polycrystalline structures, the insulator is preferably produced by deposition from a vapor. Also, in devices with polycrystalline channels, the channel material may be deposited upon the insulator or the insulator may be deposited upon the channel.

The fabrication techniques for insulated-gate field effect transistors are similar to those used to produce planar bipolar transistors and integrated monolithic devices. Impurity diffusion techniques may be used, and the geometry may be controlled by precision masking and photolithographic techniques.

A fabrication method for a stepped insulator device may be as follows: A lightly doped P-type silicon wafer, about one inch in diameter and 0.007 inch thick, is polished on one side and the surface heavily oxidized in a furnace at about 900° C. containing a steam atmosphere to produce an oxide surface coating. The oxide surface coating that is formed is then etched away in selected areas defined by masking, using photolithographic techniques.

Next, the wafer is heated at about 1050° C. for 10 minutes in an atmosphere containing an N-type dopant, such as phosphorus, thereby forming source and drain regions spaced about 0.001 inch apart where the wafer is not covered by the oxide. The entire remaining oxide is then removed.

Then, the wafer is heated at about 900° C., in wet oxygen gas for about five hours until another, second oxide layer about 4000 Å thick is formed on the surface of the wafer. The wafer is cooled to room temperature and then reheated at about 400° C. in dry hydrogen gas for about 5 minutes to produce a desired channel characteristic. The second oxide layer is selectively removed over the source and drain regions by etching.

The oxide layer over the channel is now stepped by using a series of photolithographic and partial etching operations designed to reduce the oxide thickness. The number of these operations depends upon the requisite number of oxide steps. In this example, two steps for each unit are produced having thicknesses of about 2000 and 4000 Å, and lengths of about 0.00025 and 0.00075 inch respectively.

Metal is evaporated over the entire wafer, and then selectively etched from all areas of the wafer except over the source region, the drain region and the stepped oxide regions. The metal oxide over the stepped oxide between the source region and the drain region constitutes the gate of the device. The wafer is then diced into separate units or arrays. The units or arrays are mounted on a suitable support and conductors are bonded thereto, as by thermal compression. After bonding, the units are encapsulated.

Devices incorporating the principles of the invention, prepared as described above, retained within 8%, their initial operating characteristics after 162 hours of operation at room temperature with 16.5 volts applied between source and drain and -22.5 volts applied between source and gate. This is at least a two fold improvement in stability on the average over comparable devices. At higher operating temperatures the difference in stability between the prior art devices and those embodying the invention was more marked.

The devices of the invention are improved over the prior offset gate devices by having greater operational stability. This improved operational stability is achieved by providing the thicker insulator portion adjacent the drain. It is believed that the surface ions, which are believed to cause the operational variations, are displaced further from the channel, where the electric fields are displaced further from the channel, where the electric fields therefrom have a lesser influence on the drain current through the channel.

In the embodiments in which the thicker portion of the insulator is covered either by the gate, or by a separate conductor, the ordinarily uncovered insulator is electrostatically shielded, thereby providing an environment which tends further to stabilize the characteristics of the device. The devices of the invention are improved over full gate devices (ones having a gate opposite the entire channel and uniformly spaced therefrom) by having a higher output impedance, a higher breakdown voltage from source-to-drain, and a lower feedback capacitance (capacitance between gate and drain).

WHAT WE CLAIM IS:—

1. A field-effect transistor having a channel, a source and a drain connected to said channel, and a gate spaced from said channel by insulator material characterized by said insulator material extending over the entire area between said source and said drain and being thicker opposite the portion of the channel adjacent the drain and thinner opposite the portion of channel adjacent the source, said gate extending over said thinner portion of said insulator material.

2. A field-effect transistor in accordance with Claim 1 characterized in that said gate also extends over said thicker portion of said insulator material.

3. A field-effect transistor in accordance with Claim 1 characterized in that a separate conductor is provided and is arranged over said thicker portion of said insulator material.

4. A field-effect transistor in accordance with either of Claims 1 or 3 characterized in that said gate is nonsymmetrically disposed between the source and drain connection so that a portion of said gate is opposite a por-



polycrystalline material, such as cadmium sulfide, cadmium selenide, or tellurium, preferably produced as deposition from a vapor. For such polycrystalline structures, the insulator is preferably produced by deposition from a vapor. Also, in devices with polycrystalline channels, the channel material may be deposited upon the insulator or the insulator may be deposited upon the channel.

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WHAT WE CLAIM IS:—

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2. A field-effect transistor in accordance with Claim 1 characterized in that said gate also extends over said thicker portion of said insulator material.

3. A field-effect transistor in accordance with Claim 1 characterized in that a separate conductor is provided and is arranged over said thicker portion of said insulator material.

4. A field-effect transistor in accordance with either of Claims 1 or 3 characterized in that said gate is nonsymmetrically disposed between the source and drain connection so that a portion of said gate is opposite a por-

tion of said source and a portion of said channel adjacent said drain is not opposite any portion of said gate.

5. A field-effect transistor in accordance with any one of the preceding claims in combination with biasing means connected to said source and said drain for establishing a flow of charge carriers in said channel from said source to said drain.

charge

10 6. A field-effect transistor in accordance with Claim 3 characterized in that said gate

electrode over said thinner portion is connected to said separate conductor over said thicker portion of said insulator material.

7. A field-effect transistor substantially as described herein with respect to the accompanying drawings. 15

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