

**SEMICONDUCTOR INTEGRATED CIRCUIT AND METHOD FOR
MANUFACTURING THE SAME**

Field of the Invention:

The present invention relates to semiconductor
5 integrated circuit devices and methods for
manufacturing the same and, more particularly, to a
technique effectively used for semiconductor
integrated circuit devices having a static memory
(SRAM; static random access memory) and logic
10 circuits.

BACKGROUND OF THE INVENTION

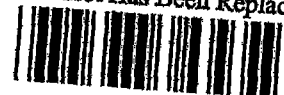
An SRAM is a memory utilizing a flip-flop
circuit as a memory element the bi-stable states of
which are respectively stored in association with "1"
15 and "0" of information, and it is characterized in
that it is easy to use because it requires no refresh
operation unlike a DRAM (dynamic random access
memory). The flip-flop circuit is formed by two
inverter circuits. The output of one of the inverter
20 circuits is electrically connected to the input of the
other inverter circuit, and the output of the other
inverter circuit is electrically connected to the
input of first inverter circuit. Each of the inverter
circuits includes a driving transistor that
25 contributes to the storage of information and a load

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element for supplying a power supply voltage to the driving transistor. Further, the flip-flop circuit is provided between a pair of data lines, and its structure is employed in which a transfer transistor
5 is interposed between the flip-flop circuit and each of the data lines to electrically connect or electrically disconnect the flip-flop circuit and the data lines.

Memory cells for such an SRAM are categorized
10 into high resistance load type cells and CMIS (complementary metal insulator semiconductor) type cells depending on the load elements in the memory cells. In the high resistance load type, a polysilicon resistor is used as a load element. In
15 this case, since the resistor occupies a small area and can be overlaid on a driving transistor or the like, the total area of a memory cell region can be minimized to provide a large capacity. On the other hand, a p-channel type MISFET is used as a load
20 element in the CMIS type, which minimizes the power consumption of the same. Some CMIS type memory cells have the so-called TFT (thin film transistor) structure in which two polysilicon layers are provided on a layer above of an n-channel type MOSFET serving
25 as a driving transistor and in which a p-channel type



MOSFET to be used as a load element is formed by the polysilicon layers to also reduce the total area of the memory cell region.

For example, a semiconductor integrated circuit
5 device having an SRAM is described in Japanese Patent Laid-Open No. 167655/1996. In order to integrate high performance logic circuits and a highly integrated CMOS type memory cell array in the same chip without increasing the complexity of manufacturing processes;
10 a structure is disclosed in which logic circuits are formed by a top channel type n-channel MOSFET and p-channel MOSFET and in which a memory cell is formed by directly connecting the gate electrodes of the n-channel MOSFET and p-channel MOSFET having the same
15 conductivity.

International Publication No. W97/38444
discloses an adjustment on the threshold voltage of a transfer transistor of an SRAM.

20 SUMMARY OF THE INVENTION

The inventor has found that the above-described technique for semiconductor integrated circuit device having an SRAM has the following problems.

Specifically, semiconductor integrated circuit
25 devices having an SRAM have had a problem in that no



sufficient attention has been paid to the need for setting separate threshold voltages for elements forming memory cells and other elements that arises from the trend toward higher speeds, lower power consumption and higher integration of elements and in that semiconductor integrated circuit devices have operational faults in the memory circuit which have not been revealed in the past when they are manufactured considering only ease of manufacture.

For example, semiconductor integrated circuit devices having an SRAM and logic circuits provided on the same semiconductor substrate are under increasing efforts toward logic circuits and SRAM peripheral circuits (hereinafter referred to "logic circuits and the like") having higher speeds and toward lower power consumption and higher integration of the semiconductor integrated circuit devices as a whole. Efforts are being put made to decrease the threshold voltage of the logic circuits and the like in order to increase the speed of the same. However, when the threshold voltages of a logic circuit and the like and a memory circuit are set at the same step taking only factors such as ease of manufacture into consideration without considering the significant trend toward increased speed of a logic circuit and the like and



lower power consumption of a semiconductor integrated circuit device, the noise margin of memory cells in the memory circuit is reduced although the operating speed of the logic circuit and the like can be improved. Studies made by the inventors have revealed that this causes operational faults of the memory circuit which have not occurred even with the threshold voltages of the logical circuit and the like and the memory circuit set at the same step.

10 It is an object of the invention to provide a technique which makes it possible to improve the operational margin of a memory of a semiconductor integrated circuit device having an SRAM.

15 It is another object of the invention to provide a technique which makes it possible to reduce the power consumption of a semiconductor integrated circuit device having an SRAM.

20 It is an object of the invention to provide a technique which makes it possible to improve the margin of writing to a memory of a semiconductor integrated circuit device having an SRAM.

The above and other objects and novel features of the invention will be apparent from the description of the specification and the accompanying drawings.

25 Typical aspects of the invention disclosed in

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this specification can be briefly described as follows.

A semiconductor integrated circuit device according to the invention is a semiconductor
5 integrated circuit device having a plurality of first field effect transistors forming a memory cell of an SRAM and a second field effect transistor other than them provided on a semiconductor substrate, in which the threshold voltage of at least one first field
10 effect transistor among said plurality of first field effect transistors is relatively higher than the threshold voltage of said second field effect transistor.

A method for manufacturing a semiconductor
15 integrated circuit device according to the invention is a method for manufacturing a semiconductor integrated circuit device having a plurality of first field effect transistors forming a memory cell of an SRAM and a second field effect transistor other than
20 them formed on a semiconductor substrate, which includes an impurity introduction step for selectively introducing a first impurity into a region to form at least one of said first field effect transistors on said semiconductor substrate in order to set the
25 threshold voltage of said at least one first field



effect transistor among said plurality of first field effect transistors relatively higher than the threshold voltage of said second field effect transistor.

5 A method for manufacturing a semiconductor integrated circuit device according to the invention is a method for manufacturing a semiconductor integrated circuit device having a plurality of first field effect transistors forming a memory cell of an.
10 SRAM and a second field effect transistor other than them formed on a semiconductor substrate, which includes a step of selectively introducing nitrogen into the region to form said second field effect transistor on said semiconductor substrate and
15 thereafter forming a gate insulation film on said semiconductor substrate in order to set the threshold voltage of said at least one first field effect transistor among said plurality of first field effect transistors relatively higher than the threshold
20 voltage of said second field effect transistor.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an illustration for explaining a configuration of circuit blocks of a semiconductor
25 integrated circuit device which is a mode for carrying



out the invention.

Fig. 2 is a circuit diagram of a memory cell in an SRAM on the semiconductor integrated circuit device in Fig. 1.

5 Fig. 3 is a plan view of a major part of a memory cell region of the SRAM of the semiconductor integrated circuit device in Fig. 1.

Fig. 4 is a plan view of a layer above that shown in Fig. 3 in the memory cell region of the SRAM
10 of the semiconductor integrated circuit device in Fig. 1.

Fig. 5 is a sectional view of a major part of the semiconductor integrated circuit device in Fig. 1 at a manufacturing step of the same.

15 Fig. 6 is a plan view of a major part of the semiconductor integrated circuit device in Fig. 1 at a manufacturing step subsequent to that shown in Fig. 5.

Fig. 7 is a sectional view of a major part of the memory cell region of the SRAM of the
20 semiconductor integrated circuit device in Fig. 1 at a manufacturing step subsequent to that shown in Fig. 6.

Fig. 8 is a sectional view of a major part of the semiconductor integrated circuit device in Fig. 1 at a manufacturing step subsequent to that shown in
25 Fig. 7.

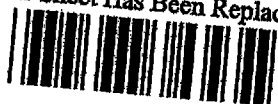
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Fig. 9 is a sectional view of a major part of the semiconductor integrated circuit device in Fig. 1 at a manufacturing step subsequent to that shown in Fig. 8.

5 Fig. 10 is a sectional view of a major part of the semiconductor integrated circuit device in Fig. 1 at a manufacturing step subsequent to that shown in Fig. 9.

10 Fig. 11 is a sectional view of a major part of the semiconductor integrated circuit device in Fig. 1 at a manufacturing step subsequent to that shown in Fig. 10.

15 Fig. 12 is a sectional view of a major part of the semiconductor integrated circuit device in Fig. 1 at a manufacturing step subsequent to that shown in Fig. 11.

20 Fig. 13 is a sectional view of a major part of the semiconductor integrated circuit device in Fig. 1 at a manufacturing step subsequent to that shown in Fig. 12.

Fig. 14 is a sectional view of a major part of the semiconductor integrated circuit device in Fig. 1 at a manufacturing step subsequent to that shown in Fig. 13.

25 Fig. 15 is a sectional view of a major part of

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the semiconductor integrated circuit device in Fig. 1
at a manufacturing step subsequent to that shown in
Fig. 14.

Fig. 16 is a sectional view of a major part of
5 the semiconductor integrated circuit device in Fig. 1
at a manufacturing step subsequent to that shown in
Fig. 15.

Fig. 17 is a sectional view of a major part of
the semiconductor integrated circuit device in Fig. 1
10 at a manufacturing step subsequent to that shown in
Fig. 16.

Fig. 18 illustrates SNM characteristics of the
semiconductor integrated circuit device in Fig. 1.

Fig. 19 illustrates SNM characteristics of a
15 technique studied by the inventor for comparison to
explain the effects of the semiconductor integrated
circuit device in Fig. 1.

Fig. 20 is a graph showing the relationship
between a threshold voltage and an SNM of a driving
20 field effect transistor in the SRAM of the
semiconductor integrated circuit device in Fig. 1.

Fig. 21 is a plan view of a major part of memory
cells of an SRAM of a semiconductor integrated circuit
device which is another mode for carrying out the
25 invention at a manufacturing step of the same.



Fig. 22 is a plan view of a major part of memory cells of an SRAM of a semiconductor integrated circuit device which is still another mode for carrying out the invention at a manufacturing step of the same.

5 Fig. 23 is a sectional view of a major part of a semiconductor integrated circuit device which is another mode for carrying out the invention at a manufacturing step of the same.

10 Fig. 24 is a sectional view of a major part of the semiconductor integrated circuit device at a manufacturing step subsequent to that shown in Fig. 23.

15 Fig. 25 is a sectional view of a major part of the semiconductor integrated circuit device at a manufacturing step subsequent to that shown in Fig. 24.

Fig. 26 is a graph for explaining SNM characteristics of an SRAM.

20 Fig. 27 is a graph of SNM characteristics of a semiconductor integrated circuit device studied by the inventor.

25 Fig. 28 is a graph showing the relationship between the drain currents of a transfer field effect transistor and a field effect transistor for load resistance forming an SRAM of a semiconductor



integrated circuit device studied by the inventor.

Fig. 29 is a graph showing the relationship between the drain currents of a transfer field effect transistor and a field effect transistor for load
5 resistance forming an SRAM of a semiconductor integrated circuit device studied by the inventor.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Modes for carrying out the invention will now be
10 described in detail with reference to the drawings (parts having like functions are given like reference numbers throughout the drawings presented to describe modes for carrying out the invention and will not be described repeatedly).

15

Embodiment 1:

Figs. 1 through 4 are illustrations for explaining a structure of a semiconductor integrated circuit device according to the invention. Figs. 5
20 through 17 are sectional views of major parts of the semiconductor integrated circuit device during manufacturing steps for explaining a method for manufacturing the semiconductor integrated circuit device in Fig. 1. Fig. 18 is an illustration for
25 explaining the effects of the present mode for

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carrying out the invention. Fig. 19 illustrates a technique studied by the inventor to explain the effects of the present mode for carrying out the invention. Fig. 20 is an illustration for explaining the effects of the present mode for carrying out the invention.

In the context of the technical principle of the art, when it is stated that "a threshold voltage (hereinafter abbreviated as "Vth") is high", it means an intentional increase of Vth beyond an increase in Vth attributable to a dimensional difference in a channel width or the like. Further, in the context of the technical principle of the art, Vth represents a gate voltage that appears when there is a flow of current of 1.0 μ A per a unit channel width (e.g., per a width of 1 μ m).

According to the technical principle of the invention, in a semiconductor integrated circuit device having MISFETs (metal insulator semiconductors) constituting an SRAM (static random access memory) and other MISFETs constituting a logic circuit such as microprocessor (CPU) provided on the same semiconductor substrate as shown in Fig. 1, a separate Vth is set for each of the MISFETs forming an SRAM and other MISFETs. This is based on the results of



studies made by the inventor as described below. For example, random bit faults have occurred in memory cells of an SRAM as a result of a trend toward higher operational speeds and lower power consumption (i.e.,
5 lower power supply voltages) of semiconductor integrated circuit devices having an SRAM and a logic circuit and the like on the same semiconductor substrate and toward higher degrees of integration of elements. Upon making the studies, the inventor found
10 a fault mode in which such memory cells have a small operational margin as a major cause of such faults. A further study indicated that potential problems had been actualized with the trend toward higher speeds and lower power supply voltages of such semiconductor
15 integrated circuit devices or higher degrees of integration of elements.

Specifically, in order to increase the speed of the logic circuit and the like of a semiconductor integrated circuit device as described above, V_{th} is
20 normally decreased. However, when V_{th} of the logic circuit and the like and the memory circuit is set at the same step taking only the aspects of ease of manufacture and the like into consideration without considering the significant trend toward higher speeds
25 of logic circuits and the like, lower power

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consumption of semiconductor integrated circuit devices or higher degrees of integration of elements, V_{th} of MISFETs in the memory cell region is also decreased to cause operational faults in the memory which have not been revealed even with the V_{th} of the logic circuit and the like and the memory circuit set at the same step.

Especially, when an isolation structure (shallow trench isolation) based on the LOCOS (local oxidation of silicon) process is replaced by a trench type buried isolation structure in order to achieve a higher degree of integration of elements, the MISFETs exhibit reverse narrow channel characteristics which result in a low V_{th} . If the V_{th} of the logic circuit and the like and the memory circuit is set at the same step without considering the same and taking only the ease of manufacture into consideration, the V_{th} of the MISFETs in the memory cell region significantly decreases to cause operational faults in said memory which have not been revealed.

Fig. 26 is waveforms showing the operational stability of a memory cell, e.g., waveforms obtained by plotting a voltage at one of the nodes of a memory cell in a 6 MISFET type SRAM relative to a voltage applied to the other node in an overlapping



relationship (transfer curves). A region where the curves overlap each other represents a margin for noises, and the length of such an overlapping region (the region which is longest in the direction at an angle of 45°) is a static noise margin (SNM). The greater the overlap (i.e., the greater the SNM), the memory operates with higher stability. However, when the V_{th} of a MISFET for driving a memory cell is as low as the V_{th} of the logic circuit and the like particularly with the V_{th} of the logic circuit and the like and the memory circuit set at the same step, the SNM is small as shown in Fig. 27, which makes the operation of the memory unstable.

Figs. 28 and 29 are graphs showing the results of measurement of the drain currents of a transfer MISFET for a memory cell and a MISFET to be used as load resistance. Those figures indicate that a read fault occurs at the transfer MISFET when the V_{th} is too high or too low and that a write fault occurs at the MISFET used as load resistance when the V_{th} is too low. That is, the inventor found that it is preferable to set not only the V_{th} of a MISFET for driving a memory cell but also the V_{th} of the transfer MISFET and MISFET used as load resistance separately from the V_{th} of the logic circuit and the like,



depending on the operational environment, operating conditions and the like.

Next, a description will be made on a structure of a semiconductor integrated circuit device according to the present mode for carrying out the invention with reference to an application of such a technical principle of the invention to a microprocessor having an SRAM for, for example, a cache memory as an example.

Fig. 1 shows a major circuit block provided in a semiconductor chip IC according to the present mode for carrying out the invention. Specifically, the semiconductor chip IC includes, for example, an input/output circuit I/O, logic circuits, such as microprocessor (CPU), 2A through 2C, an SRAM for a cache memory, a phase locked loop circuit PLL, a clock pulse generation circuit CPG and the like. The power supply voltage of a high potential side of this semiconductor integrated circuit device is, for example, 2.5 V or less. The minimum gate length of MISFETs forming this semiconductor integrated circuit device is, for example, about 0.25 μm . For example, the V_{th} of MISFETs which must be fast is 0.25 V or less.

For example, a plurality of 6 MISFET (metal



insulator semiconductor field effect transistor) type memory cells MC as shown in Fig. 2 are provided in a memory cell region of the SRAM. The memory cells MC are provided in the vicinity of crosses of a pair of complementary data lines DL1, DL2 (DL) and a word line WL and include a pair of driving MISFETs Qd1, Qd2 (Qd; first field effect transistor), a pair of MISFETs QL1, QL2 (QL; first field effect transistor) used as load resistance and a pair of transfer MISFETs Qt1, Qt2 (Qt; first field effect transistor). The pair of complementary data lines DL1, DL2 transmit signals which are inversions of each other.

Said pair of driving MISFETs Qd1, Qd2 and the pair of MISFETs QL1, QL2 used as load resistance form a flip-flop circuit. The flip-flop circuit is a memory cell which stores one bit of information ("1" or "0") and which is electrically connected to a power supply Vdd at a high potential side at one end thereof (the side of the MISFETs QL1, QL2 used as load resistance) and is electrically connected to a power supply GND at a ground side at the other end (the side of the driving MISFETs Qd1, Qd2). For example, the voltage of the power supply Vdd at the high potential side is about 1.8 V, and the voltage of the power supply GND at the ground side is 0 V.



The pair of transfer MISFETs Qt1, Qt2 are switching elements for electrically connecting and disconnecting the flip-flop circuit to and from the data lines DL1, DL2 and are interposed between input and output terminals of the flip-flop circuit (accumulation nodes N1, N2) and the data lines DL1, DL2, respectively. The gate electrodes of the pair of transfer MISFETs Qt1, Qt2 are electrically connected to the word line WL.

Figs. 3 and 4 show plan views of a major part of the memory cell region. While Fig. 4 illustrates the same position as that in Fig. 3 as a plan view, it illustrates first layer wiring above the layer shown in Fig. 3 and second layer wiring as a sectional viewed.

A semiconductor substrate 3 is made of, for example, p-type silicon (Si). P-wells and n-wells to be described later are formed on the semiconductor substrate 3. Isolation portions 4 are formed on the principle surface of the semiconductor substrate 3. Transfer MISFETs Qt, driving MISFETs Qd and MISFETs for load resistance QL are formed in active regions surrounded by the isolation portions 4. The transfer MISFETs Qt and driving MISFETs Qd are constituted by, for example, n-channel MISFETs, and the MISFETs for



load resistance QL are constituted by, for example, p-channel MISFETs. In Fig. 3, nMIS represents a region where n-channel MISFETs are formed, and pMIS represents a region where p-channel MISFETs are formed. In the present mode for carrying out the invention, the designed channel widths of the driving MISFETs Qd, transfer MISFETs Qt and MISFETs for load resistance QL are smaller than the designed channel width of MISFETs forming logic circuits and SRAM peripheral circuits (second field effect transistors). The term "designed" implies the fact that some error may be included.

The transfer MISFETs Qt include an n-type semiconductor region 5 and a gate electrode 6gt; the driving MISFETs Qd include an n-type semiconductor region 5 and a gate electrode 6gd; and the MISFETs for load resistance QL include a p-type semiconductor region and a gate electrode 6gL.

The n-type semiconductor regions 5 are regions where the sources and drains of the transfer MISFETs Qt and driving MISFETs Qd are formed and are formed by introducing, for example, phosphorus (P) or arsenic (As) into said p-wells. One of such n-type semiconductor regions 5 is a region shared by a transfer MISFET Qt and a driving MISFET Qd which



functions as wiring to electrically connect both of the MISFETs. The other n-type semiconductor region 5 of the transfer MISFET Qt is electrically connected to a data line DL (see Fig. 4) through a connection hole 8A for the data line. The data lines DL are made of, for example, aluminum, aluminum-silicon-copper alloy or the like and are formed in the second wiring layer. The n-type semiconductor regions 5 shared by transfer MISFETs Qt and driving MISFETs Qd are connected to the gate electrodes 6gdm 6gL of other driving MISFETs Qd and MISFETs for load resistance QL which are to be paired therewith through connection holes 8B and are electrically connected to first layer wiring 9L (see Fig. 4). The first layer wiring 9L is made of, for example, aluminum, aluminum-silicon-copper or the like and is connected to one of p-type semiconductor regions 7 of a load resistance MISFET QL through a connection hole 8C. The other n-type semiconductor regions 5 of the driving MISFETs Qd are electrically connected to first layer wiring 9LG (see Fig. 4) for the power supply GND at the low potential side (see Fig. 2) through connection holes 8D. The other p-type semiconductor regions 7 of the load resistance MISFET QL are electrically connected to first layer wiring 9LV (see Fig. 4) for the power supply Vdd at the high



potential side (see Fig. 2) through connection holes 8E.

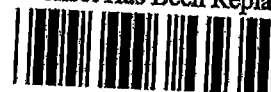
The gate electrodes 6gt of the transfer MISFETs Qt are constituted by a part of word lines WL and are in the form of planar band-shaped patterns extending horizontally in Fig. 3. The gate electrodes 6gd, 6gL of the driving MISFETs Qd and MISFETs for load resistance QL are formed in a part of an integral gate pattern. A part of this gate pattern extends diagonally to gate pattern portions connecting the gate electrodes 6gd, 6gL and is formed in a planar Y-shaped configuration as a whole. The ends of the diagonally extending portions of the gate pattern are electrically connected to the n-type semiconductor regions 5 and the first layer wiring 9L through said connection holes 8B to function as wiring. One memory cell MC has two gate patterns which are adjacent to each other in the horizontal direction of Fig. 3. The gate electrodes 6gt, 6gL are formed on a gate insulation film to be described later and are constituted by, for example, a single film of low resistance polysilicon, a multi-layer film formed by providing a silicide layer made of tungsten silicide or the like on a low resistance polysilicon film or a multi-layer film formed by providing a metal film such



as tungsten on a low resistance polysilicon film with titanium nitride, tungsten nitride or the like interposed therebetween.

A description will now be made with reference to Figs. 5 through 17 on an example of a method for manufacturing a semiconductor integrated circuit device according to the present mode for carrying out the invention. Throughout the drawings, I/O-NMIS represents a region where an n-channel type MISFET for forming an input/output circuit is formed; I/O-PMIS represents a region where a p-channel type MISFET for forming the input/output circuit is formed; logic-NMIS represents a region where an n-channel type MISFET for a logic circuit is formed; and logic-PMIS represents a region where a p-channel type MISFET for the logic circuit is formed. Examples of regions where driving MISFETs and MISFETs for load resistance are formed are shown in the memory cell region shown in Figs. 5 through 17.

For example, as shown in Fig. 5, a p-type semiconductor substrate (a semiconductor wafer at this stage) 3 having a specific resistance on the order of $10 \Omega\text{cm}$ is first subjected to wet oxidation at 800°C to form a thin silicon oxide film 10 having a thickness of about 10 nm on the surface thereof and, thereafter,



a silicon nitride film 11 having a thickness of about 200 nm is deposited thereon using the CVD (chemical vapor deposition) method. The silicon oxide film 10 is formed to moderate stress that acts on the semiconductor substrate 3 when silicon oxide films embedded in element isolating grooves are sintered (vitrified) at a later step. Since the silicon nitride film 11 has the property of resisting oxidation, it is used as a mask to prevent oxidation of the substrate surface thereunder (active region).

Subsequently, the silicon nitride film 11, silicon oxide film 10 and semiconductor substrate 3 are subjected to dry etching using a photoresist film as a mask to form isolation grooves 4a having a depth of about 300 to 400 nm on the semiconductor substrate 3 in element isolation regions. The isolation grooves 4a may be formed by performing dry etching of the silicon nitride film 11 using a photoresist film as a mask, removing the photoresist film, and thereafter performing dry etching of the silicon oxide film 10 and semiconductor substrate 3 using the patterned silicon nitride film 11 as a mask.

Next, in the present mode for carrying out the invention, a process (hereinafter referred to as "first process") as described below is performed to set

the V_{th} of driving MISFETs, transfer MISFETs and MISFETs for load resistance forming memory cells of an SRAM, relatively and intentionally higher than the V_{th} of predetermined MISFETs of SRAM peripheral circuits and logic circuits.

The photoresist film for forming the isolation grooves is first removed and, in order to set the V_{th} of the driving MISFETs and transfer MISFETs relatively and intentionally higher, a photoresist pattern 12A is formed such that regions where the driving MISFETs Qd and transfer MISFETs Qt are to be formed are exposed on the semiconductor substrate 3 and such that regions other than them are covered as shown in Fig. 6. Fig. 6 shows the same memory cell region as in Fig. 3.

Although elements and the like have not been formed yet at the stage shown in Fig. 6, they are shown here for better clarity of the position where the photoresist pattern 12A is formed. Further, the photoresist pattern 12A in Fig. 6 is hatched for better clarity of the drawing. The pattern configuration of the photoresist pattern 12A is not limited to that shown here and, for example, the pattern may be formed into a configuration which exposes the regions to form the driving MISFETs Qd and transfer MISFETs Qt and also exposes the regions of n-



channel type MISFETs formed on the semiconductor substrate 3, especially regions to form MISFETs for which any leak current between the source and drain must be suppressed, and which covers other regions.

5 Subsequently, for example, boron difluoride (BF_2) ions are implanted into the semiconductor substrate 3 using the photoresist pattern 12A as a mask. This is carried out under conditions as described below, although they are not limiting the
10 invention. Specifically, the ion implantation energy is about 40 keV; the dose is about $1 \times 10^{12}/\text{cm}^2$; and ion implantation angle is about 10 degrees. The ions are implanted at an angle in order to increase the V_{th} of the active region as a whole by introducing the
15 impurity ions into the sides of the isolation grooves 4a. The ion implantation angle is the angle at which the impurity ions impinge upon the principle surface of the semiconductor substrate 3.

Next, after removing the photoresist pattern
20 12A, a photoresist pattern 12B is formed which exposes the regions to form the MISFETs for load resistance Q_L on the semiconductor substrate 3 as shown in Fig. 7 in order to relatively and intentionally increase the V_{th} of the MISFETs for load resistance Q_L , and which
25 covers other regions. Fig. 7 also shows the same

memory cell region as in Fig. 3. Although elements and the like have not been formed yet at this stage, they are shown here to clearly show the position where the photoresist pattern 12B is formed. Further, the photoresist pattern 12B in Fig. 7 is also hatched for better clarity of the drawing. The pattern configuration of the photoresist pattern 12B is not limited to that shown here and, for example, the pattern may be formed into a configuration which exposes the regions to form the MISFETs for load resistance Q_L and also exposes the regions of p-channel type MISFETs formed on the semiconductor substrate 3, especially regions to form MISFETs for which any leak current between the source and drain must be suppressed, and which covers other regions.

Subsequently, for example, phosphorus (P) ions are implanted into the semiconductor substrate 3 using the photoresist pattern 12B as a mask. This may be carried out under the same conditions as for the introduction of the impurity to relatively and intentionally increase the V_{th} of the driving MISFETs Q_d as described above, although they are not limiting the invention. Thereafter, the photoresist pattern 12B is removed.

The order of the process of introducing an

impurity to increase the V_{th} of the driving MISFETs Qd and the like as described above and the process of introducing an impurity to increase the V_{th} of the MISFETs for load resistance QL may be reversed.

5 The V_{th} s of the driving MISFETs Qd, transfer MISFETs Qt and MISFETs for load resistance QL are relatively and intentionally increased by performing such a series of processes.

 After such a first process, in order to remove
10 any damaged layer produced on the inner walls of the isolation grooves 4a as a result of said etching, the semiconductor substrate 3 is subjected to dry oxidation at about 1000°C to form thin silicon oxide films having a thickness of about 30 nm on the inner
15 walls of the isolation grooves 4a. Subsequently, as shown in Fig. 8, a silicon oxide film 13 having a thickness of about 400 nm on the semiconductor substrate 3 is deposited and, thereafter, the semiconductor substrate 3 is subjected to wet
20 oxidation to perform sintering (vitrification) for improving the quality of the silicon oxide films 13 embedded in the isolation grooves 4a. For example, the silicon oxide film 13 is deposited using a plasma CVD process that utilizes ozone (O_3) and
25 tetraethoxysilane (TEOS) as source gases.



Next, a CVD process is performed to deposit a silicon nitride film having a thickness of about 200 nm on the silicon oxide films 13, and the silicon nitride film is thereafter subjected to dry etching using a photoresist film as a mask to leave silicon nitride films 14 only on isolation grooves 4a having relatively large areas, e.g., boundaries between the memory array and the peripheral circuits. The silicon nitride films 14 left on the isolation grooves 4a are formed in order to prevent a phenomenon (dishing) that the silicon oxide films 13 in isolation grooves 4a having relatively large areas are polished to a greater depth than the silicon oxide films 13 in isolation grooves having relatively smaller areas when the silicon oxide films 13 are polished and planarized using a chemical mechanical polishing (CMP) process at the next step.

Subsequently, after the photoresist film for patterning the silicon nitride films 14 is removed, a CMP process is carried out using the silicon nitride films 11, 14 as stoppers to polish and leave the silicon oxide films 13 in the isolation grooves 4a, thereby forming the isolation portions 4. While a reduction in the V_{th} of the MISFETs forming memory cells attributable to reverse narrow channel



characteristics should normally be inevitable because a groove type isolating structure is employed as a structure for the isolation portions 4, this mode for carrying out the invention is free from such a problem because it involves said first process or a process to be described later for relatively and intentionally increasing the V_{th} of the MISFETs forming the memory cells.

Thereafter, the silicon nitride films 11, 14 are removed, and a pre-oxidation process is carried out on the semiconductor substrate 3 to form a gate insulation film having a thickness of about 10 nm on the semiconductor substrate 3. Then, as shown in Fig. 9, a photoresist pattern 12C is formed which exposes the buried regions on the principle surface of the semiconductor substrate 3 and covers other regions and, for example, phosphorus ions are implanted into the semiconductor substrate 3 using the photoresist pattern 12C as a mask to form an n-type buried region 15 on the semiconductor substrate 3. While the n-type buried region 15 has not been formed yet at this stage because a thermal process for the activation of the impurity and the like have not been performed on the semiconductor substrate 3, the region is illustrated here for clarity of the description.

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Next, after removing the photoresist pattern 12C, a photoresist pattern is formed which exposes n-well regions throughout the principle surface of the semiconductor substrate 3 and covers other regions.

5 Subsequently, for example, phosphorus ions are implanted into the semiconductor substrate 3 using the photoresist pattern as a mask. Two kinds of impurity introduction steps are separately performed here which are a step of introducing said impurity for forming at
10 least n-wells 16NW and a step of introducing said impurity for setting the V_{th} of MISFETs formed in n-wells 16NW in regions other than the memory cell region. Thereafter, the photoresist pattern is removed.

15 Next, as shown in Fig. 10, a photoresist pattern 12D is formed which exposes p-well regions throughout the principle surface of the semiconductor substrate 3 and covers other regions. Subsequently, for example, boron or boron difluoride ions are implanted into the
20 semiconductor substrate 3 using the photoresist pattern 12D as a mask. Two kinds of impurity introduction steps are separately performed here which are a step of introducing said impurity for forming at least p-wells 16PW and a step of introducing said
25 impurity for setting the V_{th} of MISFETs formed in p-



wells 16PW in regions other than the memory cell region. Thereafter, the photoresist pattern 12D is removed.

After said step of introducing the impurity for wells and the like, a process (hereinafter referred to as "second process") as described below may be performed instead of the above-described first process to relatively and intentionally increase the V_{th} of said driving MISFETs, transfer MISFETs and MISFETs for load resistance beyond the V_{th} of predetermined MISFETs of the SRAM peripheral circuits and logic circuits.

First, in order to set the V_{th} of the driving MISFETs and transfer MISFETs relatively and intentionally higher, said photoresist pattern 12A shown in Fig. 6 (or a photoresist pattern as a modification thereof). Although elements and the like have not been formed yet also at this stage, they are shown here for better clarity of the position where the photoresist pattern 12A is formed.

Subsequently, for example, boron difluoride (BF_2) ions are implanted into the semiconductor substrate 3 using the photoresist pattern 12A as a mask. This is carried out under conditions as described below, although they are not limiting the



invention. Specifically, the ion implantation energy is about 60 keV; the dose is about $3 \times 10^{12}/\text{cm}^2$; and ion implantation angle is about 90 degrees (i.e., perpendicular to the principle surface of the semiconductor substrate 3).

Next, after removing the photoresist pattern 12A, said photoresist pattern 12B shown in Fig. 7 (or a modification of the same) is formed in order to relatively and intentionally increase the V_{th} of the MISFETs for load resistance Q_L . Although elements and the like have not been formed yet also at this stage, they are shown here to clearly show the position where the photoresist pattern 12B is formed.

Subsequently, for example, phosphorus (P) ions are implanted into the semiconductor substrate 3 using the photoresist pattern 12B as a mask. The conditions may be the same as said conditions for the introduction of the impurity to relatively and intentionally increase the V_{th} of the driving MISFETs Q_d and the like in the second process as except that the ion implantation energy is, for example, about 40 keV, although this is not limiting the invention.

The order of the process of introducing an impurity to increase the V_{th} of the driving MISFETs Q_d and the like as described above and the process of

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intriducing an impurity to increase the V_{th} of the MISFETs for load resistance Q_L may be reversed also in this case.

The V_{th} s of the driving MISFETs Q_d , transfer
5 MISFETs Q_t and MISFETs for load resistance Q_L are relatively and intentionally increased by performing such a series of processes.

After such a second process, a thermal process is performed on the semiconductor substrate 3 to carry
10 out the activation of the impurity introduced into the semiconductor substrate 3 and the like, thereby forming the n-wells 16NW, p-wells 16PW and n-type buried region 15 on the semiconductor substrate 3.

The process then proceeds to the step of forming
15 the gate insulation film and, in this mode for carrying out the invention, the step of forming the gate insulation film may be preceded by a process as described below (hereinafter referred to as "third process") which replaces the above-described first
20 process or second process to relatively and intentionally increase the V_{th} of said driving MISFETs, transfer MISFETs and MISFETs for load resistance beyond the V_{th} of predetermined MISFETs of the SRAM peripheral circuits and logic circuits.

25 First, a photoresist pattern is formed which



exposes regions to form MISFETs whose operating speed must be increased in the regions of the peripheral circuits and logic circuits and which covers regions to form MISFETs for which any leak current between the
5 source and drain must be suppressed throughout the memory cell region and in the regions of the peripheral circuits and logic circuits.

Subsequently, for example, nitrogen (N) ions are implanted into the semiconductor substrate 3 using the
10 photoresist pattern as a mask. This is carried out under conditions as described below, although they are not limiting the invention. Specifically, the ion implantation energy is about 5 keV; the dose is about $4 \times 10^{14}/\text{cm}^2$; and ion implantation angle is about 90
15 degrees.

It is thus possible to set the V_{th} of the driving MISFETs, transfer MISFETs and MISFETs for load resistance in the memory cell region relatively and intentionally higher. The reason is as follows.
20 Specifically, the V_{th} of a MISFET decreases when nitrogen is included in the gate insulation film thereof. Further, in a region doped with nitrogen, the gate insulation film is nitrised to have increased anti-oxidation properties and therefore becomes
25 thinner than the gate insulation film in a region



which is not doped with nitrogen. The V_{th} of a MISFET whose gate insulation film is formed in a region doped with nitrogen can be made relatively smaller than the V_{th} of a MISFET whose gate insulation film is formed
5 in a region which is not doped also in this aspect.

Since nitrogen is segregated on the interface between the gate insulation film and the semiconductor substrate 3 in a region doped with nitrogen, an advantage can be obtained in that the reliability of
10 the gate insulation film can be improved. It is known that a reduction in the thickness of a gate insulation film causes a distortion of the interface between the gate insulation film and the semiconductor substrate 3 attributable to the difference between the thermal
15 expansion coefficients of itself and the semiconductor substrate 3 to induce the generation of hot carriers. The reason for the above is that such a distortion is moderated by the nitrogen segregated on the interface to the semiconductor substrate 3. Since the problem
20 of hot carriers is unlikely to occur in a memory cell region, no particular problem occurs even if a memory cell region is not doped with nitrogen.

While the present mode for carrying out the invention has referred to a case wherein said third
25 process is carried out instead of said first process



or second process, this is not limiting the invention and the third process may be carried out in combination with the first process or second process.

After such a third process, the process proceeds
5 to, for example, a step of forming gate insulation films as described below.

First, an oxidation process for forming the gate insulation films of MISFETs having a high withstand voltage formed on the semiconductor substrate 3 is
10 performed to form gate insulation films having the maximum relative thickness of, for example, 9 nm or more on the principle surface of the semiconductor substrate 3. Subsequently, a photoresist pattern is formed on the gate insulation film to cover the region
15 to form the MISFETs having a high withstand voltage and to expose other regions and, thereafter, the thick gate insulation film exposed from the photoresist pattern is removed and the photoresist pattern is reduced further.

20 While the process normally proceeds thereafter to a step of forming the gate insulation films of MISFETs other than the MISFETs having a high withstand voltage, according to the present mode for carrying out the invention, a process as described below
25 (hereinafter referred to as "fourth process") may be

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performed in addition to said first process, second process or third process in order to set the V_{th} of said driving MISFETs, transfer MISFETs and MISFETs for load resistance relatively and intentionally higher than the V_{th} of predetermined MISFETs of the SRAM peripheral circuits and logic circuits.

First, an oxidation process for forming the gate insulation films of MISFETs forming memory cells and MISFETs for which any leak current between the source and drain must be suppressed is carried out to form gate insulation films having an intermediate relative thickness of, for example, about 5 nm on the principle surface of the semiconductor substrate 3. The thickness of the gate insulation films is made greater than the thickness of gate insulation films formed on regions to form MISFETs whose operating speed must be increased in the regions of peripheral circuits and logic circuits. This makes it possible to relatively and intentionally increase the V_{th} of the MISFETs forming memory cells and said MISFETs for which any leak current must be suppressed.

Subsequently, a photoresist pattern is formed on the gate insulation films having an intermediate thickness to cover regions to form said MISFETs for which any leak current must be suppressed in the



entire memory cell region, peripheral circuit regions and logic circuit regions and to expose other regions and, thereafter, the gate insulation films having an intermediate thickness exposed from the photoresist pattern is removed and the photoresist pattern is removed further.

Thereafter, an oxidation process for forming the gate insulation films of MISFETs which must operate at a high speed on the semiconductor substrate 3 is performed to form gate insulation films having the minimum relative thickness less than, for example, 5 nm on the principle surface of the semiconductor substrate 3.

Next, as shown in Fig. 11, a conductive film 18 for forming gate electrodes is formed on the semiconductor substrate 3 using a CVD process or the like to cover gate insulation films 17 formed as described above and the upper surface of the isolation portions 4. For example, the conductive film 18 is constituted by a single film made of low resistance polysilicon, a multi-layer film formed by coating low resistance polysilicon with a tungsten silicide film or a multi-layer film formed by coating low resistance polysilicon with a metal film such as tungsten with a barrier metal film such as tungsten nitride or



titanium nitride interposed therebetween. Said
barrier metal film functions as a barrier layer for
preventing the tungsten film and polysilicon film from
reacting to each other during a high temperature
5 thermal process to form a high resistance silicide
layer at the interface between them.

Subsequently, a photoresist pattern 12E is
formed on the conductive film 18 to expose regions to
form n-channel type MISFETs in the memory cell region
10 and other regions and to cover other regions and, for
example, phosphorus ions are implanted into the
conductive film 18 using it as a mask. Thereafter,
after removing the photoresist pattern 12E, a capping
insulation film made of, for example, silicon oxide or
15 silicon nitride is deposited on the conductive film 18
using a CVD process or the like.

Next, after patterning the capping insulation
film with a photoresist pattern as a mask using a dry
etching process or the like, the photoresist pattern
20 is removed; the conductive film 18 is patterned using
the patterned capping insulation film as a mask; and
the capping insulation film 19 is removed further to
form gate electrodes 6g as shown in Fig. 12. The
capping insulation film and the conductive film 18 are
25 patterned at one time using a photolithographic



technique and a dry etching technique to form the gate electrodes 6g (6gd, 6gL) and the capping insulation film. In this case, the capping insulation film is left on the gate electrodes 6g. The minimum gate
5 length for the gate electrodes 6g is set at a minimum dimension (for example, $0.24\ \mu$) within a tolerance in which the short channel effect of MISFETs can be suppressed to maintain the V_{th} of the same at a predetermined value or more.

10 Next, for example, phosphorus (P) ions are implanted into the p-wells 16PW using a photoresist pattern as a mask as shown in Fig. 13 to form n⁻-type semiconductor regions 5a in the p-wells 16PW on both sides of the gate electrodes 6g. While the n⁻-type
15 semiconductor regions 5a are not formed at this stage because no thermal process for activation and the like has been performed, they are shown here for better understanding of the description.

Subsequently, after removing the photoresist
20 pattern, for example, boron (B) ions are implanted into the n-wells 16NW using a newly formed photoresist pattern 12F as a mask to form p⁻-type semiconductor regions 7a in the n-wells 16NW on both sides of the gate electrodes 6g. While the p⁻-type semiconductor
25 regions 7a are not formed at this stage because no

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thermal process for activation and the like has been performed, they are shown here for better understanding of the description.

Next, after removing the photoresist pattern
5 12F, a thermal process is carried out for the activation of the impurities introduced into the semiconductor substrate 3; as shown in Fig. 14, a silicon nitride film having a thickness of about 50 nm is deposited thereafter on the semiconductor substrate
10 3 using a CVD process or the like; and the silicon nitride film is then subjected to anisotropic etching to form side walls spacers 19 on the side walls of the gate electrodes 6g. This etching is carried out using an etching gas that promotes the etching of a silicon
15 nitride film at a rate greater than that for a silicon oxide film in order to minimize the amount of removal of the gate insulation films 17 and the silicon oxide films buried in the isolation portions 4. When the capping insulation film constituted by a silicon
20 nitride film is formed on the gate electrodes 6g, the amount of overetching is also limited to the required minimum in order to minimize the amount of removal of the same.

Next, for example, arsenic (A) ions are
25 implanted into the p-wells 16PW using a photoresist

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pattern as a mask to form n^+ -type semiconductor regions 5b of n-channel type MISFETs. While the n^+ -type semiconductor regions 5b are not formed at this stage because no thermal process for activation and the like has been performed, they are shown here for better understanding of the description. The n-type semiconductor regions 5 shown in Fig. 3 and etc. are constituted by the n^- -type semiconductor regions 5a and n^+ -type semiconductor regions 5b.

Subsequently, after removing the photoresist pattern, for example, boron (B) ions are implanted into the n-wells 16NW using a newly formed photoresist pattern 12G as a mask to form p^+ -type semiconductor regions 7b of p-channel type MISFETs. While the p^+ -type semiconductor regions 7b are not formed at this stage because no thermal process for activation and the like has been performed, they are shown here for better understanding of the description. The p-type semiconductor regions 7 shown in Fig. 3 and etc. are constituted by the p^- -type semiconductor regions 7a and p^+ -type semiconductor regions 7b.

Next, after removing the photoresist pattern 12G, a thermal process is carried out for the activation of the impurities introduced into the semiconductor substrate 3 to form p-channel type



MISFETs Qp, QL and n-channel type MISFETs Qn, Qd.

Next, a conductive film made of titanium nitride (TiN), cobalt (Co) or the like is deposited on the semiconductor substrate 3 using a sputtering process or the like, and a thermal process is performed thereafter to form a silicide layer 20 at the interface between the conductive film and the semiconductor substrate 3 and the gate electrodes 6g as shown in Fig. 15. Subsequently, a thermal process is performed again after removing the conductive film which has not been silicified.

Next, an insulation film 21a constituted by a silicon nitride film or the like is deposited on the semiconductor substrate 3 using a CVD process or the like; an insulation film 21b made of PSG (phospho silicate glass) is deposited thereon using a CVD process or the like; and an insulation film 21c made of, for example, silicon oxide is further deposited thereon. Subsequently, after planarizing the upper surface of the insulation film 21c using a CMP process, connection holes 8 are formed in a part of the insulation films 21a - 21c. Thereafter, for example, titanium, titanium nitride and tungsten are deposited on the semiconductor substrate 3 in the order of precedence in stacking and are etched back



thereafter using a CMP process to bury and form
conductive films 22 in the connection holes 8.

Next, for example, titanium, aluminum or an
aluminum alloy, titanium and titanium nitride are
5 deposited on the semiconductor substrate 3 in the
order of precedence in stacking and are thereafter
patterned using a photolithographic technique and a
dry etching technique to form first layer wiring 9L.
Subsequently, second layer wiring 23L and third layer
10 wiring 24L are formed similarly to said first layer
wiring 9L. Reference numbers 21d, 21e represent, for
example, insulation films made of silicon oxide. A
normal method for manufacturing a semiconductor
integrated circuit device is hereafter used to
15 manufacture a microprocessor incorporating an SRAM for
a cache memory.

The effects of the present mode for carrying out
the invention will now be described with reference to
Figs. 18 through 20.

20 Fig. 18 shows a transfer curve in a case wherein
the V_{th} of MISFETs forming memory cells is relatively
and intentionally increased as in the present mode for
carrying out the invention, and Fig. 19 shows a
transfer curve in a case wherein the V_{th} is not
25 increased. Fig. 20 shows an SNM for the V_{th} of



driving MISFETs.

As apparent from a comparison between the transfer curves in Figs. 18 and 19, the present mode for carrying out the invention makes it possible to
5 improve an SNM significantly. Especially, as apparent from Figs. 18 through 20, when the first process or second process is performed to increase the V_{th} of driving MISFETs, the SNM is abruptly increased and a sufficient operational margin can be maintained for
10 the memory cells.

Thus, the following effects can be achieved by the mode 1 for carrying out the invention.

(1) In a microprocessor incorporating an SRAM, since the V_{th} of driving MISFETs, transfer MOSFETs and
15 MISFETs for load resistance for memory cells of the SRAM is relatively and intentionally increased, the SNM of the SRAM can be improved while improving the operating speed of the microprocessor, reducing the power supply voltage (i.e., reducing the power
20 consumption) and improving the degree of element integration as a result of the use of a groove type isolation structure.

(2) It is possible to reduce the rate of occurrence of read faults and write faults of the
25 memory in the microprocessor incorporating an SRAM.

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(3) According to the above (1), (2), it is possible to improve the reliability of the operation of a microprocessor incorporating an SRAM which is compact, which has high performance and which can
5 operate at a high speed with small power consumption.

Embodiment 2:

Fig. 21 is a plan view of major parts of a semiconductor integrated circuit device which is
10 another mode for carrying out the invention taken during the manufacture of the same.

While said mode 1 for carrying out the invention has referred to a case in which the V_{th} of all MISFETs that form memory cells of an SRAM is relatively and
15 intentionally increased, the invention is not limited thereto, and the V_{th} of predetermined MISFETs of the memory cells of the SRAM may be relatively and intentionally increased.

The mode 2 for carrying out the invention
20 describes it and, for example, in order to increase the V_{th} of transfer MISFETs relatively and intentionally, a photoresist pattern 12A2 may be formed on the semiconductor substrate 3 as shown in Fig. 21 instead of the photoresist pattern 12A shown
25 in Fig. 6 at said first process or second process



described in said mode 1 for carrying out the invention such that regions to form the transfer MISFETs are exposed and other regions are covered. Fig. 21 shows the same memory cell region as in Figs. 3, 6 and etc. and shows elements and the like for clearly showing the position where the photoresist pattern 12A2 is formed as in the above description. The photoresist pattern 12A2 is also hatched in Fig. 21 for better clarity of the figure. Further, the configuration of the photoresist pattern 12A2 is not limiting the present invention and, for example, the pattern may be formed in a configuration which exposes regions to form the transfer MISFETs Qt and regions to form n-channel type MISFETs formed in the semiconductor substrate 3, especially regions to form MISFETs for which any leak current between the source and drain must be suppressed and which covers other regions.

According to such a mode 2 for carrying out the invention, especially, it is possible to reduce the rate of occurrence of read faults of a memory while improving the operating speed of a microprocessor incorporating an SRAM, reducing the power supply voltage (i.e., reducing the power consumption) and improving the degree of element integration. It is



therefore possible to improve the reliability of the operation of a microprocessor incorporating an SRAM which is compact, which has high performance and which can operate at a high speed with small power
5 consumption.

Embodiment 3:

Fig. 22 is a plan view of major parts of a semiconductor integrated circuit device which is
10 another mode for carrying out the invention taken during the manufacture of the same.

The mode 3 for carrying out the invention is a case wherein describes the V_{th} of driving MISFETs is to be relatively and intentionally increased and, in
15 this case, a photoresist pattern 12A3 may be formed on the semiconductor substrate 3 as shown in Fig. 22 instead of the photoresist pattern 12A (see Fig. 6) at said first process or second process described in said mode 1 for carrying out the invention such that
20 regions to form the driving MISFETs are exposed and other regions are covered. Fig. 22 also shows the same memory cell region as in Figs. 3, 6 and etc. and shows elements and the like for clearly showing the position where the photoresist pattern 12A3 is formed
25 as in the above description. The photoresist pattern



12A3 is also hatched in Fig. 22 for better clarity of the figure. Further, the configuration of the photoresist pattern 12A3 is not limiting the present invention and, for example, the pattern may be formed in a configuration which exposes regions to form the driving MISFETs Qd and regions to form n-channel type MISFETs formed in the semiconductor substrate 3, especially regions to form MISFETs for which any leak current between the source and drain must be suppressed, and which covers other regions.

According to such a mode 3 for carrying out the invention, especially, it is possible to improve the SNM of an SRAM while improving the operating speed of a microprocessor incorporating an SRAM, reducing the power supply voltage (i.e., reducing the power consumption) and improving the degree of element integration. It is therefore possible to improve the reliability of the operation of a microprocessor incorporating an SRAM which can operate at a high speed with small power consumption.

Embodiment 4:

Figs. 23 through 25 are plan views of major parts of a semiconductor integrated circuit device which is another mode for carrying out the invention



taken during the manufacture of the same.

The mode 4 for carrying out the invention describes a modification of the third process described in said mode 1 for carrying out the
5 invention. Specifically, while said third process describes a case wherein nitrogen is introduced into a semiconductor substrate using ion implantation, nitrogen is segregated on the interface between gate insulation films and a semiconductor substrate by
10 mixing nitrogen gas in the atmosphere of a thermal process in the mode 4 for carrying out the invention, and the specific method for the same is as follows.

First, as shown in Fig. 23, gate insulation films 17 made of, for example, silicon oxide are
15 formed on the principle surface of a semiconductor substrate 3 using a normal gate oxidation process; a photoresist pattern 12H is formed on the principle surface of the semiconductor substrate 3 to cover the memory cell region and to expose other regions; and
20 the gate insulation films 17 exposed therefrom are removed using it as an etching mask.

The photorsist pattern 12H is then removed to leave the gate insulation films 17 only in the memory cell region as shown in Fig. 24. Thereafter, a gate
25 oxidation process is performed on the semiconductor



substrate 3, for example, in an NO (nitrogen oxide) or N₂O (nitrogen monoxide) atmosphere to form the gate insulation films 17 (17a, 17b) as shown in Fig. 25. Thus, nitrogen is segregated on the interface between
5 the gate insulation films 17 and the semiconductor substrate 3 (nitrogen oxide process).

In this case, since the gate insulation film 17a in the memory cell region is thicker than the gate insulation film 17b in other regions, the
10 concentration of nitrogen is relatively higher in the thinner gate insulation film 17b than in the thicker gate insulation film 17a. As a result, the V_{th} of MISFETs formed in the memory cell region can be relatively and intentionally higher than the V_{th} of
15 MISFETs formed in other regions. Further description will be omitted because it will be the same as that on said mode 1 for carrying out the invention.

Such a mode 4 carrying out the invention makes it possible to achieve the same effects as those
20 available in the mode 1 for carrying out the invention.

While the invention conceived by the inventor has been specifically described based on modes for carrying out the same, the invention is not limited to
25 said modes for carrying out the invention and may



obviously modified in various ways without departing from the principle thereof.

For example, the semiconductor wafer is not limited to single films made of silicon single
5 crystals and may be modified in various ways. For example, an epitaxial wafer may be used which is obtained by forming a thin epitaxial layer (of 1 μm , for example) on the surface of a semiconductor substrate made of silicon single crystals and,
10 alternatively, an SOI (silicon on insulator) wafer may be used which is obtained by providing a semiconductor layer for forming elements on an insulated layer.

While the above description has been made on applications of the invention made by the inventor to
15 microprocessors incorporating an SRAM memory cells which involve the field of application that is the background of the invention, the invention is not limited thereto and may be applied to, for example, semiconductor integrated circuit devices and the like
20 constituted solely by an SRAM. Further, while said modes for carrying out the invention have referred to the use of 6 MISFET type SRAM cells, the invention is not limited thereto and, for example, it is possible to use high resistance load type SRAM cells utilizing
25 polysilicon resistors as load resistance elements and



SRAM cells having the so-called TFT structure in which two polysilicon layers are provided on driving MISFETs to form a p-channel type MOSFET used as a load resistance element with the polysilicon layers. It may
5 also be applied to semiconductor devices in which MISFETs forming an SRAM and other circuits, and bipolar transistors are formed on a semiconductor substrate.

Effects provided by typical aspects of the
10 invention disclosed in the present specification can be briefly described as follows.

(1) The present invention makes it possible to improve the static noise margin (SNM) of an SRAM while improving the operating speed of a microprocessor
15 incorporating an SRAM and reducing the power supply voltage of the same (i.e., reducing the power consumption).

(2) The present invention makes it possible to reduce the rate of occurrence of read faults and write
20 faults of a memory of a microprocessor incorporating an SRAM.

(3) According to the above (1), (2), it is possible to improve the reliability of operation of a microprocessor incorporating an SRAM which can operate
25 at a high speed with small power consumption.





What is claimed is:

1. A semiconductor integrated circuit device comprising:

5 a plurality of first field effect transistors constituting a memory cell of an SRAM and provided on a semiconductor substrate; and

second field effect transistors other than said first field effect transistors provided on said semiconductor substrate,

10 wherein the threshold voltage of at least one first field effect transistor among said plurality of first field effect transistors is relatively higher than the threshold voltage of said second field effect transistor.

15 2. A semiconductor integrated circuit device comprising a driving field effect transistor, a transfer field effect transistor and a load field effect transistor constituting a memory cell of an SRAM and provided on a semiconductor substrate; and

20 another field effect transistor provided on said semiconductor integrated circuit,

wherein the threshold voltage of at least two of or all of said driving field effect transistor, transfer field effect transistor or load field effect
25 transistor is relatively higher than the threshold





voltage of said other field effect transistor.

3. A semiconductor integrated circuit device comprising a driving field effect transistor constituting a memory cell of an SRAM and provided on
5 a semiconductor substrate; and

another field effect transistor provided on said semiconductor substrate,

wherein the threshold voltage of said transfer field effect transistor is relatively higher than the
10 threshold voltage of said other field effect transistor.

4. A semiconductor integrated circuit device comprising a driving field effect transistor constituting a memory cell of an SRAM and provided on
15 a semiconductor substrate; and

another field effect transistor provided on said semiconductor substrate,

wherein the threshold voltage of said transfer field effect transistor is relatively higher than the
20 threshold voltage of said other field effect transistor with a designed thickness of a gate insulation film of said transfer field effect transistor being the same as a designed thickness of a gate insulation film of said other field effect
25 transistor.

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5. A semiconductor integrated circuit device comprising a load field effect transistor constituting a memory cell of an SRAM and provided on a semiconductor substrate; and

5 another field effect transistor provided on said semiconductor substrate,

wherein the threshold voltage of said load field effect transistor is relatively higher than the threshold voltage of said other field effect transistor.

6. A semiconductor integrated circuit device according to Claim 1, wherein the operating speed thereof is 100 MHz or more.

7. A semiconductor integrated circuit device according to Claim 1, wherein an isolation portion provided on said semiconductor substrate has a groove type structure.

8. A semiconductor integrated circuit device according to Claim 1, wherein a designed channel width of at least one of said first field effect transistor is smaller than a designed channel width of said second field effect transistor.

9. A method for manufacturing a semiconductor integrated circuit device having a plurality of first field effect transistors constituting a memory cell of

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an SRAM and second field effect transistor other than them formed on a semiconductor substrate, comprising:

an impurity introduction step for selectively introducing a first impurity into a region to form at least one of said first field effect transistors on said semiconductor substrate in order to set the threshold voltage of said at least one first field effect transistor among said plurality of first field effect transistors relatively higher than the threshold voltage of said second field effect transistor.

10. A method for manufacturing a semiconductor integrated circuit device having a plurality of first field effect transistors constituting a memory cell of an SRAM and second field effect transistors other than them formed on a semiconductor substrate, which comprising:

(a) a step of forming a groove on said semiconductor substrate;

(b) an impurity introduction step for selectively introducing a first impurity into a region to form at least one of said first field effect transistors on said semiconductor substrate in order to set the threshold voltage of said at least one first field effect transistor among said plurality of

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first field effect transistors relatively higher than the threshold voltage of said second field effect transistor;

(c) a step of forming an isolation portion by
5 burying an insulation film in said groove after said step (b); and

(d) an impurity introduction step for selectively introducing a second impurity into a region to form field effect transistors of the same
10 conductivity type on said semiconductor substrate in order to set the threshold voltage of said second field effect transistor, after said step (c).

11. A method for manufacturing a semiconductor integrated circuit device having a plurality of first
15 field effect transistors constituting a memory cell of an SRAM and second field effect transistors other than them formed on a semiconductor substrate, which comprising:

(a) a step of forming a groove on said
20 semiconductor substrate;

(b) a step of forming an isolation portion by burying an insulation film in said groove after said step of forming a groove;

(c) an impurity introduction step for
25 selectively introducing a first impurity into a region

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to form at least one of said first field effect transistors on said semiconductor substrate in order to set the threshold voltage of said at least one first field effect transistor among said plurality of first field effect transistors relatively higher than
5 the threshold voltage of said second field effect transistor, after said step (b); and

(d) an impurity introduction step for selectively introducing a second impurity into a
10 region to form field effect transistors of the same conductivity type on said semiconductor substrate in order to set the threshold voltage of said second field effect transistor, after said step (c).

12. A method for manufacturing a semiconductor
15 integrated circuit device according to Claim 9, wherein said at least one field effect transistor is a driving field effect transistor.

13. A method for manufacturing a semiconductor integrated circuit device having a plurality of first
20 field effect transistors constituting a memory cell of an SRAM and second field effect transistor other than them formed on a semiconductor substrate, which comprising:

(a) a step of forming a gate insulation film on
25 said semiconductor substrate;

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(b) a step of forming a photoresist pattern on the semiconductor substrate after said step (a) to cover the regions to form said first field effect transistors and to expose other regions, and
5 thereafter removing the gate insulation film exposed by the same used as a mask; and

(c) a step of removing said photoresist pattern after said step (b) and thereafter performing an oxidation process on said semiconductor substrate to
10 form, in the regions to form said first field effect transistors, a gate insulation film thicker than a gate insulation film formed in the region to form said second field effect transistor,

thereby setting the threshold voltage of at
15 least one first field effect transistor among said plurality of first field effect transistors relatively higher than the threshold voltage of said second field effect transistor.

14. A method for manufacturing a semiconductor
20 integrated circuit device having a first field effect transistor constituting a memory cell of an SRAM and a second field effect transistor other than it formed on a semiconductor substrate, which comprising:

(a) a step of selectively introducing a first
25 impurity into the region to form said at least one





first field effect transistor on said semiconductor substrate; and

(b) a step of forming, in the region to form said at least first field effect transistor, a gate insulation film thicker than a gate insulation film formed in the region to form said second field effect transistor, on said semiconductor substrate, thereby setting the threshold voltage of at least one first field effect transistor among said plurality of first field effect transistors relatively higher than the threshold voltage of said second field effect transistor.

15. A method for manufacturing a semiconductor integrated circuit device having a plurality of first field effect transistors constituting a memory cell of an SRAM and second field effect transistor other than them formed on a semiconductor substrate, which comprising:

(a) a step of forming a groove on said semiconductor substrate;

(b) an impurity introduction step for selectively introducing a first impurity into a region to form at least one of said first field effect transistors on said semiconductor substrate in order to set the threshold voltage of said at least one

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first field effect transistor among said plurality of first field effect transistors relatively higher than the threshold voltage of said second field effect transistor, after said step (a);

- 5 (c) a step of forming an isolation portion by burying an insulation film in said groove after said step of forming a groove after said step (b);

- (d) an impurity introduction step for selectively introducing a second impurity into a
10 region to form field effect transistors of the same conductivity type on said semiconductor substrate in order to set the threshold voltage of said second field effect transistor, after said step (c);

- (e) a step of forming a gate insulation film on
15 the semiconductor substrate after said step (d);

- (f) a step of forming a photoresist pattern on the semiconductor substrate after said step (e) to cover the regions to form said first field effect transistors and to expose other regions, and
20 thereafter removing the gate insulation film exposed by the same used as a mask; and

- (g) a step of removing said photoresist pattern after said step (f) and thereafter performing an oxidation process on said semiconductor substrate to
25 form, in the regions to form said first field effect

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transistors, a gate insulation film thicker than a gate insulation film formed in the region to form said second field effect transistor.

16. A method for manufacturing a semiconductor integrated circuit device having a plurality of first field effect transistors constituting a memory cell of an SRAM and a second field effect transistor other than them formed on a semiconductor substrate, which comprising:

10 (a) a step of forming a groove on said semiconductor substrate;

(b) a step of forming an isolation portion by burying an insulation film in said groove after said step of forming a groove;

15 (c) an impurity introduction step for selectively introducing a first impurity into a region to form at least one of said first field effect transistors on said semiconductor substrate in order to set the threshold voltage of said at least one first field effect transistor among said plurality of first field effect transistors relatively higher than the threshold voltage of said second field effect transistor, after said step (b);

20 (d) an impurity introduction step for selectively introducing a second impurity into a

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region to form field effect transistors of the same conductivity type on said semiconductor substrate in order to set the threshold voltage of said second field effect transistor, after said step (b);

5 (e) a step of forming a gate insulation film on the semiconductor substrate after said step (d);

 (f) a step of forming a photoresist pattern on the semiconductor substrate after said step (e) to cover the regions to form said first field effect
10 transistors and to expose other regions, and thereafter removing the gate insulation film exposed by the same used as a mask; and

 (g) a step of removing said photoresist pattern after said step (f) and thereafter performing an
15 oxidation process on said semiconductor substrate to form, in the regions to form said first field effect transistors, a gate insulation film thicker than a gate insulation film formed in the region to form said second field effect transistor.

20 17. A method for manufacturing a semiconductor integrated circuit device having a plurality of first field effect transistors constituting a memory cell of an SRAM and second field effect transistor other than them formed on a semiconductor substrate, which
25 comprising:

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a step of selectively introducing nitrogen into the region to form said second field effect transistor on said semiconductor substrate and thereafter forming a gate insulation film on said semiconductor

5 substrate,

thereby setting the threshold voltage of at least one first field effect transistor among said plurality of first field effect transistors relatively higher than the threshold voltage of said second field effect

10 transistor.

18. A method for manufacturing a semiconductor integrated circuit device having a plurality of first field effect transistors constituting a memory cell of an SRAM and second field effect transistor other than

15 them formed on a semiconductor substrate, which comprising:

(a) a step of selectively introducing a first impurity into the region to form said at least one first field effect transistor on said semiconductor
20 substrate; and

(b) a step of selectively introducing nitrogen into the region to form said second field effect transistor on said semiconductor substrate and thereafter forming a gate insulation film on said
25 semiconductor substrate,

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thereby setting the threshold voltage of at least one first field effect transistor among said plurality of first field effect transistors relatively higher than the threshold voltage of said second field effect transistor.

19. A method for manufacturing a semiconductor integrated circuit device having a plurality of first field effect transistors constituting a memory cell of an SRAM and second field effect transistor other than them formed on a semiconductor substrate, which comprising:

(a) a step of forming a groove on said semiconductor substrate;

(b) an impurity introduction step for selectively introducing a first impurity into a region to form at least one of said first field effect transistors on said semiconductor substrate in order to set the threshold voltage of said at least one first field effect transistor among said plurality of first field effect transistors relatively higher than the threshold voltage of said second field effect transistor, after said step (a);

(c) a step of forming an isolation portion by burying an insulation film in said groove after said step of forming a groove after said step (b);



(d) an impurity introduction step for selectively introducing a second impurity into a region to form field effect transistors of the same conductivity type on said semiconductor substrate in
5 order to set the threshold voltage of said second field effect transistor, after said step (c); and

(e) a step of selectively introducing nitrogen into the region to form said second field effect transistor on said semiconductor substrate and
10 thereafter forming a gate insulation film on said semiconductor substrate, after said step (d).

20. A method for manufacturing a semiconductor integrated circuit device having a plurality of first field effect transistors constituting a memory cell of
15 an SRAM and second field effect transistor other than them formed on a semiconductor substrate, which comprising:

(a) a step of forming a groove on said semiconductor substrate;

20 (b) a step of forming an isolation portion by burying an insulation film in said groove after said step of forming a groove;

(c) an impurity introduction step for selectively introducing a first impurity into a region
25 to form at least one of said first field effect

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transistors on said semiconductor substrate in order
to set the threshold voltage of said at least one
first field effect transistor among said plurality of
first field effect transistors relatively higher than
5 the threshold voltage of said second field effect
transistor, after said step (b);

(d) an impurity introduction step for
selectively introducing a second impurity into a
region to form field effect transistors of the same
10 conductivity type on said semiconductor substrate in
order to set the threshold voltage of said second
field effect transistor, after said step (b); and

(e) a step of selectively introducing nitrogen
into the region to form said second field effect
15 transistor on said semiconductor substrate and
thereafter forming a gate insulation film on said
semiconductor substrate after said step (d).

21. A semiconductor integrated circuit device
according to claim 1,
20 wherein said second field effect transistors
constitute a microprocessor.

22. A semiconductor integrated circuit device
according to claim 2,
wherein said another field effect transistor
25 constitutes a microprocessor.

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23. A semiconductor integrated circuit device
according to claim 3,

wherein said another field effect transistor
constitutes a microprocessor.

5 24. A semiconductor integrated circuit device
according to claim 4,

wherein said another field effect transistor
constitutes a microprocessor.

25. A semiconductor integrated circuit device
10 according to claim 5,

wherein said another field effect transistor
constitutes a microprocessor.

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