

Semiconductor Device Comprising a Field-Effect Transistor in a Silicon-On-Insulator Structure

Field of Invention

The present invention relates to the manufacture of a field-effect transistor in a silicon-on-insulator structure and, in particular, to a system-on-chip comprising densely packed field-effect transistors that may share functional regions.

Background of the invention

Semiconductor-On-Insulator (SeOI) and, in particular, Silicon-On-Insulator (SOI) semiconductor devices are of increasing interest in present and future semiconductor manufacturing, for example, in the context of the Complementary Metal Oxide Semiconductor (CMOS) technology. In modern integrated circuits, a very high number of individual circuit elements, such as field effect transistors in the form of CMOS, NMOS, PMOS elements, resistors, capacitors, and the like are formed on a single chip area. Typically, feature sizes of these circuit elements are steadily decreasing with the introduction of every new circuit generation, to provide currently available integrated circuits with an improved degree of performance in terms of speed and/or power consumption. A reduction in size of transistors is an important aspect in steadily improving device performance of complex integrated circuits, such as CPUs. The reduction in size commonly brings about an increased switching speed, thereby enhancing signal processing performance.

During the fabrication of complex integrated circuits using CMOS technology, millions of transistors, i.e., n-channel transistors and p-channel transistors, are

formed on a substrate including a crystalline semiconductor layer. Transistor elements are the dominant circuit element in highly complex integrated circuits which substantially determine the overall performance of these devices.

A MOS transistor, irrespective of whether an n-channel transistor or a p-channel transistor is considered, comprises so-called pn-junctions that are formed by an interface of highly doped drain and source regions with an inversely or weakly doped channel region disposed between the drain region and the source region. The conductivity of the channel region, i.e., the drive current capability of the conductive channel, is controlled by a gate electrode formed near the channel region and separated therefrom by a thin insulating layer. The conductivity of the channel region upon formation of a conductive channel due to the application of an appropriate control voltage to the gate electrode, depends on the dopant concentration, the mobility of the majority charge carriers, and – for a given extension of the channel region in the transistor width direction – on the distance between the source and drain regions, which is also referred to as channel length.

Due to the decreased dimensions of circuit elements, not only the performance of the individual transistor elements may be increased, but also their packing density may be improved, thereby providing the potential for incorporating increased functionality into a given chip area. For this reason, highly complex circuits have been developed, which may include different types of circuits, such as analogue circuits, digital circuits and the like, thereby providing entire systems on a single chip (SoC).

The continuing shrinkage of the transistor dimensions, however, involves a plurality of issues associated therewith that have to be addressed so as to not unduly offset the advantages obtained by steadily decreasing the channel length of MOS transistors. One major problem in this respect is to provide for low sheet and contact resistivity in drain and source regions and any contacts connected thereto and to maintain channel controllability. For example, reducing the channel length may necessitate an increase of the capacitive coupling between the gate electrode and the channel region, which may call for re-

duced thickness of the gate insulation layer. Presently, the thickness of silicon dioxide based gate insulation layers is in the range of 1 to 2 nanometers, wherein a further reduction may be less desirable in view of leakage currents which typically exponentially increase when reducing the gate dielectric thickness.

However, the interface of the gate dielectric and polysilicon that is conventionally used for the manufacture of the gate electrode is characterized by grain boundaries affecting a uniform dopant profile and resulting in poor adhesion properties and reliability failures. Moreover, given the continually decreased dimensions of circuit elements and despite the recent engineering progress, there is still a need for more compact configurations of transistor elements of different performance properties.

In view of the above, the present disclosure relates to methods for the manufacture of semiconductor devices and semiconductor devices in which transistors may be formed in a space efficient manner and improved properties with respect to the gate dielectric – gate electrode interface.

Description of the Invention

In order to address the above-mentioned objects, it is provided a semiconductor device according to claim 1, comprising

a semiconductor-on-insulator, in particular, a silicon-on-insulator, SOI, structure comprising a substrate, an oxide layer (BOX layer) on the substrate and a semiconductor layer, in particular, a single crystal silicon layer, on the oxide layer; with

a field-effect-transistor, FET, wherein the FET comprises

a channel region in the substrate;

a dielectric being at least a part of the oxide layer of the semiconductor-on-insulator structure; and

a gate at least partially being a first part of the semiconductor layer of the semiconductor-on-insulator structure.

In one particular embodiment the dielectric is a gate dielectric and the gate is a gate electrode that, in particular, may further comprise a layer of polysilicon on the first part of the semiconductor layer (for example, the single crystal silicon layer) of the semiconductor-on-insulator structure, for example, SOI structure, that at least partially forms the gate.

In the following, description is made for an SOI structure comprising a single crystal layer. However, it is to be understood that any semiconductor-on-insulator structure without restriction to silicon can be encompassed in the present invention.

Thus according to the present invention, FETs with gate dielectrics in form of parts of initial BOX layers of SOI structures are provided that, furthermore, have gate electrodes that at least partially are formed from parts of the single crystal silicon layers of the SOI structures. Thereby, improved electrode characteristics due to the single crystal silicon are provided (in the art, usually, polysilicon only is used for the gate material) and the material properties of the interface between the dielectric and the gate electrode is significantly improved. In the art, a polysilicon – oxide interface is provided between the gate electrode and the gate dielectric. According to the present invention, a single crystal silicon – oxide interface is provided between the gate electrode and the gate dielectric, thereby avoiding grain boundaries resulting in inhomogeneous dopant profiles and affecting the long time operation reliability of high-performance transistors, as well as contributing to V_T variability. Thus the provided transistors are particularly suitable for high-voltage applications, for example, in the context of RF devices and electrostatic discharge (ESD) protections,

In another particular embodiment the FET is a floating-gate FET and the dielectric is a tunnel dielectric and the gate is a floating-gate. The floating-gate FET may further

comprise a gate dielectric on the floating gate and a gate electrode, in particular, made of polysilicon, on the gate dielectric. Again, a single crystal silicon – oxide interface can be provided this time between the floating gate and the tunnel dielectric. The single crystal silicon – oxide interface results in improved charge/data retention as compared to the conventional polysilicon – oxide interface. Thus, this embodiment is particularly suitable for the manufacture of high-voltage FLASH memory devices. Manufacture of the floating-gate FET is compatible with the manufacture of the FET comprising a part of the BOX layer as a gate dielectric and a gate electrode that is at least partly made of single crystal silicon as described above.

It should be noted that in the above-described examples the substrate of the SOI structure may be a polysilicon substrate and the BOX layer may be provided in form of a silicon dioxide layer, for example. The SOI structure may be obtained by the SMARTCUT® process.

The above-described examples for the inventive FET are particularly suitable for co-integration with conventional bulk transistors on SOI (MOSFETs). Thus, the semiconductor device according to one of the above-described examples may further comprise another FET comprising a channel region and source-drain regions both made of a second part of the silicon layer of the SOI structure. Additionally, the other FET may comprise a dielectric layer, particularly, comprising a low-k material, formed on the channel region that is located in the single crystal silicon layer of the SOI and a gate metal layer formed on this gate dielectric layer.

According to an embodiment, the first part of the silicon layer of the SOI structure is different from the second part of the silicon layer of the SOI structure and an insulator region, in particular, a shallow trench isolation, is provided separating the FET comprising the dielectric that is made from a part of the oxide layer of the SOI structure from the other FET comprising a channel region and source-drain regions both made of the second part of the single crystal silicon layer of the SOI structure. Alternatively, the first part of the single crystal silicon layer of the SOI structure and the second part of the single crystal silicon layer of the SOI structure at least partially overlap each other. In particular, the first part of the single crystal silicon layer of the SOI structure

(functioning as a gate for the inventive transistor) may form at least partially a source or drain region of the other (conventional) FET.

In both cases the process flow for the manufacture of the transistors readily allows for the co-integration of both transistor devices. When the first part of the single crystal silicon layer of the SOI structure forms at least partially a source or drain region of the other FET a very compact configuration arises that allows for minimizing the necessary space.

Moreover, the semiconductor device may comprise the FET comprising the dielectric that is made from a part of the oxide layer of the SOI structure, a conventional MOSFET separated from that FET and an additional conventional MOSFET with a source or drain region shared with the gate of the inventive FET comprising the dielectric that is made from a part of the oxide layer of the SOI structure.

In order to address the above-mentioned object the present invention also provides a method for manufacturing a semiconductor device, comprising

providing a silicon-on-insulator, SOI structure comprising a substrate, an oxide layer on the substrate and a single crystal silicon layer on the oxide layer;

forming a polysilicon layer on the single crystal silicon layer to obtain a polysilicon on SOI structure; and

etching the polysilicon on SOI structure to form a FET comprising a channel region in the substrate, a gate dielectric made from a part of the oxide layer of the SOI structure and a gate electrode at least partially made of a first part of the single crystal silicon layer of the SOI structure and a part of the polysilicon layer formed on the single crystal silicon layer. The etching may be performed based on a photoresist formed and patterned on the polysilicon layer on the SOI structure.

Whereas in the following embodiments of the inventive methods are described with reference to an SOI structure comprising a single crystal silicon layer on a buried ox-

oxide layer, in principle, any other suitable semiconductor material can be used. Thus, it is to be understood that the invention covers a semiconductor-in-insulator structure, for example, comprising germanium or silicon-germanium on an oxide layer, and is not restricted to an SOI structure.

The method may further comprise the steps

forming a mask layer on the SOI structure;

forming a shallow trench isolation through the mask layer extending to the substrate and separating a first region of the SOI structure from a second region of the SOI structure;

removing the mask layer from the second region of the SOI structure;

subsequently forming a dielectric layer on the second region of the SOI structure;

forming a metal layer on the dielectric layer; and

removing the mask layer from the first region of the SOI structure; and

etching the metal layer, the dielectric layer and the SOI structure in the second region to form a MOSFET in the second region of the SOI structure; and wherein

the polysilicon layer is formed on the single crystal silicon layer in the first region of the SOI structure to obtain the polysilicon on SOI structure and on the metal layer.

Co-integration with a conventional MOSFET can easily be realized. Thus, the method according to the above examples may further comprise manufacturing a MOSFET on the SOI structure comprising the steps of

forming a gate dielectric on the single crystal silicon layer of the SOI structure;

forming a gate electrode on the gate dielectric; and

forming source and drain regions such that one of the source and drain regions is at least partly formed of at least a part of the gate electrode that is at least partially made of the first part of the single crystal silicon layer of the SOI structure.

Moreover, it is provided a method for manufacturing a semiconductor device, comprising

providing a silicon-on-insulator, SOI structure comprising a substrate, an oxide layer on the substrate and a single crystal silicon layer on the oxide layer;

forming a dielectric layer on the single crystal silicon layer;

forming a polysilicon layer on the dielectric layer to obtain a multilayer structure; and

etching the multilayer structure to form a floating-gate FET comprising a channel region in the substrate, a tunnel dielectric made from a part of the oxide layer of the SOI structure, a floating gate made of a first part of the single crystal silicon layer of the SOI structure, a gate dielectric made of a part of the dielectric layer formed on the single crystal silicon layer and a gate electrode comprising a part of the polysilicon layer formed on the dielectric layer.

Again, the etching step may be performed based on a photoresist formed and patterned on the polysilicon layer on SOI structure

This method including the formation of a floating-gate transistor may also comprise the steps of

forming a mask layer on the SOI structure;

forming a shallow trench isolation through the mask layer extending to the substrate and separating a first region of the SOI structure from a second region of the SOI structure;

removing the mask layer from the second region of the SOI structure;

subsequently forming another dielectric layer on the second region of the SOI structure;

forming a metal layer on the other dielectric layer;

removing the mask layer from the first region of the SOI structure; and

etching the metal layer, the other dielectric layer and the SOI structure in the second region to form the MOSFET in the second region of the SOI structure; and wherein

the dielectric layer is formed on the single crystal silicon layer and the polysilicon layer is formed on the dielectric layer to obtain a multilayer structure in the first region of the SOI structure.

Again, co-integration with a conventional MOSFET can easily be realized. Thus, the method related to a floating-gate transistor according to the above examples may further comprise manufacturing a MOSFET on the SOI structure comprising the steps of

forming a gate dielectric on the single crystal silicon layer of the SOI structure;

forming a gate electrode on the gate dielectric; and

forming source and drain regions such that one of the source and drain regions is at least partly formed of at least a part of the floating gate that is at least partially made of the first part of the single crystal silicon layer of the SOI structure.

In the above-described examples of the inventive semiconductor device and method an SOI structure is involved. The SOI structure may have a BOX layer with varying thickness. In particular, the thickness of the BOX layer may be adapted to be suitable for a dielectric layer of a high-performance FET or a tunnel dielectric of a floating-gate FET.

An SOI structure with a varying thickness of the BOX layer may be obtained by

providing an SOI stack comprising a substrate layer, a first silicon (di)oxide layer on the substrate layer and a single crystal silicon layer on the first silicon (di)oxide layer;

forming a second oxide layer on the single crystal silicon layer and a mask layer on the second oxide layer;

patterning the second oxide layer and the mask layer to expose a first part of the single crystal silicon layer;

subjecting the resulting structure to an anneal process thereby partially dissolving the part of the first silicon (di)oxide layer beneath the exposed first part of the single crystal silicon layer in order to obtain a thinned silicon (di)oxide layer; and

removing the second oxide layer and the mask layer.

The thinned silicon (di)oxide layer can subsequently serve as a dielectric layer or tunnel dielectric in the above-described examples of the present invention, i.e. the part of the oxide layer of the SOI structure the gate dielectric or floating dielectric is made from is at least a part of the thinned silicon (di)oxide layer.

The high-temperature anneal process can be performed at a temperature of 900 °C to 1200 °C in an anneal ambient comprising Ar and/or N₂, thereby partially dissolving the part of the first oxide layer beneath the first thinned silicon layer in order to obtain a first thinned silicon oxide layer.

Thus, synergetically the advantage is provided to obtain an SOI structure with a BOX layer of varying thickness such that the thickness of the BOX layer can properly be adapted to fulfill standards for a gate dielectric or tunnel dielectric of a FET or floating-gate FET, respectively, that is manufactured according to the present invention.

Moreover, the thickness of the single crystal silicon layer can be adjusted to the particular needs for a reliably operating gate electrode or floating gate, respectively. In particular, the SOI structure in the above-described examples may be formed comprising the steps of

providing an SOI stack comprising a substrate layer, a first oxide layer on the substrate layer and a single crystal silicon layer on the first oxide layer;

forming a second oxide layer on the single crystal silicon layer and a mask layer on the second oxide layer;

patterning the second oxide layer and the mask layer to expose a first part of the single crystal silicon layer;

thermally oxidizing the exposed single crystal silicon layer to form a silicon oxide layer on the previously exposed single crystal silicon layer and a first thinned single crystal silicon layer; and

removing the second oxide layer and the mask layer and the silicon oxide layer formed on the previously exposed single crystal silicon layer;

and wherein first part of the silicon layer of the SOI structure is at least a part of the first thinned single crystal silicon layer.

The thermal oxidation processing can be performed in an oxygen atmosphere, in particular, comprising O_2/H_2 or $O_2/H_2/HCl$ or O_2/HCl and/or at a temperature of 800 °C to 1000 °C.

The mask layers can be nitride layers, in particular, silicon nitride layers or a stack of oxide/nitride layers. Steps of the above examples for adjusting the thickness of the BOX layer or of the single crystal silicon layer can be repeated. Thus the method comprising the anneal processing for thinning the BOX layer may further comprise the steps of forming a third oxide layer and another mask layer on the exposed first part of the single crystal silicon layer; patterning the third oxide layer and the other mask layer to expose a second part of the single crystal silicon layer; and subjecting the resulting structure to another anneal process thereby partially dissolving the part of the first thinned silicon oxide layer beneath the exposed second part of the single crystal silicon layer in order to obtain a second thinned silicon oxide layer.

Similarly, the method comprising the step of thermal oxidation for forming a thinned single crystal silicon layer may further comprise the steps of forming a second mask layer on a part of the silicon oxide layer and thermally oxidizing a part of the first thinned silicon layer located beneath the part of the silicon oxide layer that is not covered by the second mask layer thereby forming another silicon oxide layer and a second thinned single crystal silicon layer.

It should be noted that, in particular, dissolution of the buried oxide in the SOI structure is performed before the further processing comprising STI formation and dopant implantation and diffusion. The STI is arranged at the transition zones between the dissolved and originally provided BOX layer.

Additional features and advantages of the present invention will be described with reference to the drawings. In the description, reference is made to the accompanying figures that are meant to illustrate preferred embodiments of the invention. It is understood that such embodiments do not represent the full scope of the invention.

Figures 1a - 1g illustrate an example for the method for manufacturing a semiconductor device according to the present invention, wherein an FET is formed that comprises a part of a BOX layer of an SOI structure as a gate dielectric.

Figures 2a to 2g illustrate further examples for the method for manufacturing a semiconductor device according to the present invention, wherein a floating-gate FET is formed that comprises a part of a BOX layer of an SOI structure as a tunnel dielectric.

Figure 3 illustrates an example of a semiconductor device according to the present invention comprising a MOSFET and a lower positioned FET wherein the drain of the MOSFET also functions as a gate of the lower positioned FET.

Figures 4a, 4b und 4c illustrate an example for the method for manufacturing a semiconductor device according to the present invention, wherein a floating-gate FET is formed that comprises a part of a BOX layer of an SOI structure as a tunnel dielectric.

In Figures 1a – 1g show stages of an embodiment of manufacturing a semiconductor device according to the invention are shown. It is provided an SOI structure comprising a polysilicon substrate 1, an oxide layer 2 (BOX layer), for example, made of silicon dioxide, and a single crystal silicon layer 3. As shown in Figure 1b a hard mask layer 4 is grown or deposited atop of the silicon layer 3. In the shown example the hard mask layer comprises a thin oxide layer 5 and a silicon nitride layer 6. A photoresist is deposited on the hard mask layer 4 and patterned for the formation of shallow trench isolations 7. For this purpose, the hard mask layer 4, the silicon layer 3 and the BOX layer 2 are etched and the resulting trench is extended partly into the substrate 1. Then, the trench is filled by one or more dielectric materials, for example, silicon dioxide, and excess dielectric is removed from the surface of the mask layer 5 by chemical-mechanical planarization.

As shown in Figure 1c, the hard mask layer 4 is removed from regions A and C to expose the single crystal silicon layer 1 in these regions. Then, a high-k dielectric layer 8 (for example, with a dielectric constant k more than 3.9 is formed on the exposed surfaces of the single crystal silicon layer 3 and silicon nitride layer 6 of region B as well as atop of the shallow trench isolations 7 and, subsequently a metal layer 9 is formed atop of the high-k dielectric layer 8 (see Figure 1d). The high-k dielectric layer 8 may

be made of silicon nitride or a composite material (SiON , Al_2O_3 , HfO_2 , etc...) and the metal layer 9 may be made of TiN , W , TaN , and ternary components (Ti-Ta-N) etc., for example

In the stage shown in Figure 1e, the layers 8 and 9 are removed from the region B between the shallow trench isolations 7 and from the shallow trench isolations 7 and the remaining mask layer 4 is removed from the region B between the shallow trench isolations 7. Subsequently, a polysilicon layer 10 is deposited as it is shown in Figure 1f. A photoresist (not shown) is formed atop the resulting structure and patterned for etching to form gate electrodes in the regions A, B and C (see Figure 1g). In the example, shown in Figure 1g three FETs are formed. In regions A and C conventional MOSFETs 20 on SOI result. The channel regions of the conventional MOSFETs 20 are located below the gate dielectrics 8 in the silicon layer 3. Adjacent to the channel regions source and drain regions are formed by n or p carrier type dopants as known in the art. Gate electrodes of the MOSFETs 20 are formed from the metal layer 9 and also include the etched polysilicon material 10".

The inventive FET 30 is formed separated from the conventional MOSFETs 20 by the trench isolations 7. The inventive FET 30 is characterized by a gate dielectric formed from the original BOX layer 2 provided in the SOI structure shown in Figure 1a and a gate electrode that comprises single crystal silicon 3' formed from the original single crystal silicon layer 3 provided in the SOI structure shown in Figure 1a. Polysilicon layer 10' is also formed as part of the gate electrode. N or P dopants adjacent to the channel region provided in the substrate 1 below the gate dielectric provide source and drain regions. As compared to the art and MOSFETs 20 in Figure 1g in the inventive FET the BOX layer of an SOI structure is used as the gate dielectric and the single crystal silicon of the SOI structure is used as part of the gate electrode. Thereby, a better interface between the gate dielectric (silicon dioxide) and the gate electrode (single crystal silicon) as compared to the art is achieved. Operation of high-voltage high performance transistors can, thereby, be made more reliable. It is noted that depending on the desired properties of the gate dielectric the BOX layer 2 may be provided with a lower thickness in region B than in regions A and C.

Figures 2a und 2b illustrate another example for the method for manufacturing a semiconductor device according to the present invention. According to this example, a floating-gate FET is formed that comprises a part of a BOX layer of an SOI structure as a tunnel dielectric and a part of a single crystal silicon layer of the SOI structure as a floating gate. One may start from the configuration shown in Figure 1e. The exposed surface of the single crystal silicon layer 3 is thermally oxidized at some 700 °C to 900 °C, for example, in order to grow oxide dielectric layer 11 (see Figure 2a). Alternatively, a dielectric layer 11, for instance, a silicon oxide layer, may be grown or deposited on the exposed surface of the single crystal silicon layer 3. Subsequently, a polysilicon layer 10 is deposited on the metal layer 9 in regions A and C and on the dielectric layer 11.

As it was described above with reference to Figure 1g the configuration shown in Figure 2a is etched in order to form two MOSFETs 20 in regions A and B. In addition a floating-gate FET 40 is formed that is separated from the MOSFETs 20 by the shallow trench isolations 7. Due to the above-described processing steps the floating-gate FET 40 in region B comprises a channel region in the substrate 1 below the tunnel dielectric 2'. At both sides of the channel region source and drain regions are provided by appropriate doping of the substrate 1. The floating-gate FET 40, furthermore, comprises a floating gate 3' above the tunnel dielectric 2'. The floating gate 3' is separated from the gate electrode 10' by the gate dielectric 11'. As compared to conventional floating-gate FETs the better single crystal silicon – oxide (floating gate – tunnel dielectric) interface allows for improved data retention when the floating-gate FET is used as a memory device. A reliable high-voltage FLASH device can, thus, be provided. It is noted that depending on the desired properties of the tunnel dielectric the BOX layer in the starting SOI structure may be provided with a lower thickness in region B than in regions A and C.

An alternative example for the manufacture of a semiconductor device according to the present invention is illustrated in Figures 2c to 2g. The process flow starts from the structure shown in Figure 1c. A high-k dielectric layer 8 is grown or deposited on single crystal silicon layer 3 in regions A and C. A metal gate layer 9 is formed atop of the high-k dielectric layer 8 (see Figure 2c). Subsequently, a thin polysilicon layer 13 is

formed on the metal gate layer 9 in regions A and C. The formation of layers 8, 9 and 13 over regions A and C comprises continuous formation of the layers over regions A, B and C and a lithographic step for removing the layers from region B (and the insulation region 7) by employing a photoresist mask (not shown) patterned to cover regions A and C, respectively. After etching the regions exposed by the photoresist mask the configuration shown in Figure 2c results.

Subsequently, the hard mask (5 and 6) is removed in region B as is shown in Figure 2d. The thus exposed crystal silicon layer 3 is oxidized in region B to obtain an oxidized layer 11 as is shown in Figure 2e. Alternatively, a dielectric layer 11 is formed on the exposed crystal silicon layer 3. Subsequently, a polysilicon layer 10 for forming a gate electrode is deposited as it is shown in Figure 2f. Thereby, a configuration similar to the one shown in Figure 2a but including the thin polysilicon layer 13 is obtained.

Similar to the example shown in Figure 2b by means of an appropriately patterned photoresist mask an etching the structure shown in Figure 2f results. This structure comprises gate structures for circuits in regions A, B and C. In particular, the gate structures comprise the gate dielectric 8, gate metal layer 9 and both etched polysilicon gate material 10 and etched thin polysilicon layer 13 in regions A and C.

As it is described with reference to Figures 1a to 1g and Figures 2a to 2g, the inventive transistor devices can be manufactured in co-integration with conventional SOI based transistors. However, it goes without saying that the above-described exemplary examples for the manufacture of the semiconductor device may be amended in a manner not to include the formation of the conventional MOSFETs 20.

Not only co-integration of the inventive devices with conventional bulk transistors on SOI is possible but rather a new densely packed combination of different transistors is available. As it is illustrated in Figure 3 according to another example of the present invention a configuration comprising in a particular manner a conventional SOI MOSFET and an inventive FET is provided. According to the shown example, a conventional MOSFET comprising a gate electrode 100 and sidewall spacers 110 used for the formation of source and drain regions is formed according to SOI technology. The

source and drain regions of this MOSFET are designated as “top source” 120 and “top drain” 130, respectively. These top source 120 and top drain 130 regions are formed in a single crystal silicon layer 230 of the SOI structure. Insulation regions 140 are provided adjacent to the source/drain regions. The gate electrode 100 is separated from the channel region 150 that is located between the top source 120 and top drain region 130 by a gate dielectric 160. In the shown example, the contacts 170 are formed in another dielectric material 180 covering the MOSFETs. The contacts 170 provide connection to metal interconnects of a metallization layer, for example. The MOSFET is indicated by an ellipsoid dashed contour.

The single crystal silicon layer 230 is located atop of a BOX layer 190. The BOX layer 190 is located above a substrate 200, for example, a silicon substrate 200. However, according to the shown example the drain 130 of the MOSFET indicated by the ellipsoid dashed contour also functions as a gate electrode designated as “bottom gate” of an FET located partially below the MOSFET. The FET that is indicated by the ellipsoid dotted contour comprises the part of the single crystal silicon layer 230 that functions as a drain 130 for the MOSFET, a part of the BOX layer 190 functioning as a gate dielectric and a drain 210 and a source 220 region provided by appropriate dopants in the substrate 200 of the SOI structure. All of the source and drain regions of the two transistors (and thus the bottom gate of the lower positioned FET) are connected to the contacts 170. Consequently, a very compact semiconductor device comprising a MOSFET on SOI and an FET comprising a BOX layer dielectric and single crystal silicon gate electrode can be obtained.

Figures 4a to 4c illustrate an example for the method for manufacturing a semiconductor device according to the present invention, wherein a floating-gate FET that comprises a part of a BOX layer of an SOI structure as a tunnel dielectric and SOI transistors are formed.

The starting point for this exemplary inventive method is the stack shown in Figure 1a. A dielectric layer 11 is grown or deposited on crystal silicon layer 3 and a polysilicon layer 12 is formed on the dielectric layer 11 (see Figure 4a). The thin polysilicon layer 12 serves as a protection layer for the dielectric layer 11 during the further processing.

Subsequently, a dielectric layer 5 is formed on the polysilicon layer 12 and a nitride layer 6 is deposited on the dielectric layer 5. Shallow trench isolation regions are defined by lithography and trenches are etched through layers 2, 3, 11, 12, 5 and 6 and extending to the polysilicon substrate 1 and filled with some dielectric material to obtain shallow trench isolations 7. Layers 5 and 6 function as a hard mask during the process of etching the trenches. The dielectric material filled into the trenches is planarized with the nitride layer 6. The thus resulting structure is illustrated in Figure 4b.

Further processing similar to the one described with reference to Figure 1c to 1g results in the structure shown in Figure 4c. MOSFETs 20 are formed in the left and right regions of Figure 4c that are separated from the central region by shallow trench isolations 7. However, a floating-gate FET 30 comprising a floating gate 3' above a tunnel dielectric 2 wherein the floating gate 3' is separated from a gate electrode 10' by a gate dielectric 11' and thin polysilicon layer 12' is formed in the central region.

Whereas in the description of the Figures processing of an SOI structure is described a semiconductor-on-insulator structure in general can be processed according to the described inventive methods. For example, germanium, silicon-germanium, strained silicon strained silicon-germanium, etc. can be used rather than conventional silicon in the semiconductor-on-insulator structure.

All previously discussed embodiments are not intended as limitations but serve as examples illustrating features and advantages of the invention. It is to be understood that some or all of the above described features can also be combined in different ways.

Claims

1. Semiconductor device, comprising
 - a semiconductor-on-insulator, SeOI, structure, in particular, a silicon-on-insulator, SOI, structure comprising a substrate, an oxide layer on the substrate and a semiconductor layer, in particular, a single crystal silicon layer, on the oxide layer; with
 - a field-effect-transistor, FET, wherein the FET comprises
 - a channel region in the substrate;
 - a dielectric being at least a part of the oxide layer of the semiconductor-on-insulator structure; and
 - a gate at least partially being a first part of the semiconductor layer of the semiconductor-on-insulator structure.
2. The semiconductor device according to claim 1, wherein the dielectric is a gate dielectric and the gate is a gate electrode that, in particular, further comprises a layer of polysilicon on the first part of the semiconductor layer of the semiconductor-on-insulator structure.
3. The semiconductor device according to claim 1, wherein the FET is a floating-gate FET and the dielectric is a tunnel dielectric and the gate is a floating-gate.
4. The semiconductor device according to one of the preceding claims, further comprising another FET comprising a channel region and source and drain regions made of a second part of the semiconductor layer of the semiconductor-on-insulator structure.

5. The semiconductor device according to claim 4, wherein the first part of the semiconductor layer of the SeOI structure and the second part of the semiconductor layer of the SeOI structure at least partially overlap each other.
6. The semiconductor device according to claim 5, wherein the first part of the semiconductor layer of the SeOI structure forms at least partially a source or drain region of the other FET.
7. The semiconductor device according to one of the preceding claims, further comprising an additional FET comprising a channel region and source and drain regions made of a third part of the semiconductor layer of the semiconductor-on-insulator structure.
8. The semiconductor device according to claim 7, wherein the first part of the semiconductor layer of the semiconductor-on-insulator structure is different from the third part of the semiconductor layer of the semiconductor-on-insulator structure and further comprising an insulator region, in particular, a shallow trench isolation, separating the FET comprising the dielectric that is made from a part of the oxide layer of the semiconductor-on-insulator structure from the additional FET.
9. Method for manufacturing a semiconductor device, comprising

providing a semiconductor-on-insulator, SeOI, structure comprising a substrate, an oxide layer on the substrate and a semiconductor layer on the oxide layer;

forming a polysilicon layer on the semiconductor layer to obtain a polysilicon on SeOI structure; and

etching the polysilicon on SeOI structure to form a FET comprising a channel region in the substrate, a gate dielectric made from a part of the oxide layer of the SeOI structure and a gate electrode at least partially made of a first part of

the semiconductor layer of the SeOI structure and a part of the polysilicon layer formed on the semiconductor layer.

10. Method for manufacturing a semiconductor device, comprising

providing a semiconductor-on-insulator, SeOI, structure comprising a substrate, an oxide layer on the substrate and a semiconductor layer on the oxide layer;

forming a dielectric layer on the semiconductor layer;

forming a polysilicon layer on the dielectric layer to obtain a multilayer structure; and

etching the multilayer structure to form a floating-gate FET comprising a channel region in the substrate, a tunnel dielectric made from a part of the oxide layer of the SeOI structure, a floating gate made of a first part of the semiconductor layer of the SeOI structure, a gate dielectric made of a part of the dielectric layer formed on the semiconductor layer and a gate electrode comprising a part of the polysilicon layer formed on the dielectric layer.

11. The method according to claim 9, further comprising the steps

forming a mask layer on the SeOI structure;

forming a shallow trench isolation through the mask layer extending to the substrate and separating a first region of the SeOI structure from a second region of the SeOI structure;

removing the mask layer from the second region of the SeOI structure;

subsequently forming a dielectric layer on the second region of the SeOI structure;

forming a metal layer on the dielectric layer; and

removing the mask layer from the first region of the SeOI structure; and

etching the metal layer, the dielectric layer and the SeOI structure in the second region to form a MOSFET in the second region of the SeOI structure; and wherein

the polysilicon layer is formed on the semiconductor layer in the first region of the SeOI structure to obtain the polysilicon on SeOI structure and on the metal layer.

12. The method according to claim 10, further comprising the steps

forming a mask layer on the SeOI structure;

forming a shallow trench isolation through the mask layer extending to the substrate and separating a first region of the SeOI structure from a second region of the SeOI structure;

removing the mask layer from the second region of the SeOI structure;

subsequently forming another dielectric layer on the second region of the SeOI structure;

forming a metal layer on the other dielectric layer;

removing the mask layer from the first region of the SeOI structure; and

etching the metal layer, the other dielectric layer and the SeOI structure in the second region to form the MOSFET in the second region of the SeOI structure; and wherein

the dielectric layer is formed on the semiconductor layer and the polysilicon layer is formed on the dielectric layer to obtain a multilayer structure in the first region of the SeOI structure.

13. The method according to claim 9, further comprising manufacturing a MOSFET on the SeOI structure comprising the steps of

forming a gate dielectric on the single crystal silicon layer of the SeOI structure;

forming a gate electrode on the gate dielectric; and

forming source and drain regions such that one of the source and drain regions is at least partly formed of at least a part of the gate electrode that is at least partially made of the first part of the semiconductor layer of the SeOI structure.

14. The method according to claim 10, further comprising manufacturing a MOSFET on the SeOI structure comprising the steps of

forming a gate dielectric on the single crystal silicon layer of the SeOI structure;

forming a gate electrode on the gate dielectric; and

forming source and drain regions such that one of the source and drain regions is at least partly formed of at least a part of the floating gate that is at least partially made of the first part of the silicon layer of the SeOI structure.

15. The method according to one of the claims 9 to 14, wherein providing the SeOI structure comprises

providing a silicon-on-insulator, SOI, stack comprising a substrate layer, a first silicon (di)oxide layer on the substrate layer and a single crystal silicon layer on the first silicon (di)oxide layer;

forming a second oxide layer on the single crystal silicon layer and a mask layer on the second oxide layer;

patterning the second oxide layer and the mask layer to expose a first part of the single crystal silicon layer;

subjecting the resulting structure to an anneal process thereby partially dissolving the part of the first silicon (di)oxide layer beneath the exposed first part of the single crystal silicon layer in order to obtain a thinned silicon (di)oxide layer; and

removing the second oxide layer and the mask layer;

and wherein the part of the oxide layer of the SOI structure is at least a part of the thinned silicon (di)oxide layer.

16. The method according to one of the claims 9 to 15, wherein providing the SeOI structure comprises

providing an silicon-on-insulator, SOI, stack comprising a substrate layer, a first oxide layer on the substrate layer and a single crystal silicon layer on the first oxide layer;

forming a second oxide layer on the single crystal silicon layer and a mask layer on the second oxide layer;

patterning the second oxide layer and the mask layer to expose a first part of the single crystal silicon layer;

thermally oxidizing the exposed single crystal silicon layer to form a silicon oxide layer on the previously exposed single crystal silicon layer and a first thinned single crystal silicon layer; and

removing the second oxide layer and the mask layer and the silicon oxide layer formed on the previously exposed single crystal silicon layer;

and wherein first part of the silicon layer of the SOI structure is at least a part of the first thinned single crystal silicon layer.