DESCRIPTION

METHOD OF PRODUCING SIMOX SUBSTRATE AND THE SIMOX SUBSTRATE

Technical Field

The present invention relates to an SOI substrate having a buried oxide layer near a surface of a silicon substrate and a single crystal silicon surface layer (hereinafter called an SOI layer, meaning a silicon-on-insulator layer) formed thereon.

Background Art

A Separation by IMplanted OXygen (SIMOX) wafer and a bonded wafer are known as typical examples of an SOI substrate which has a single crystal silicon layer formed on an insulating material such as silicon dioxide. The SIMOX wafer is an SOI substrate obtained by: introducing oxygen ions inside a single crystal silicon substrate through the ion implantation of oxygen ions; having the oxygen ions react with silicon atoms through a subsequent annealing process; and thus forming a Buried OXide layer (hereinafter called a BOX layer). The bonded wafer, on the other hand, is an SOI substrate obtained by: bonding two single crystal silicon wafers, with an oxide layer in between; and then turning one of the two wafers into a thin film.

A Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET) formed in the SOI layer of such an SOI substrate has high radiation resistance and high latch-up resistance, shows high reliability, suppresses a short channel effect which tends to occur as a device size becomes smaller, and enables an operation with low power consumption, as well. Besides, because the operating region of a device is isolated from the substrate itself in terms of dielectric capacitance, signal transmission speed is enhanced, and thus high-speed operation of the

device is realized. For those reasons, the SOI substrate has been the most promising canditate of a high performance semiconductor substrate for MOS-LSIs of the next generation.

Among the variety of the SOI substrates, the SIMOX wafer has an advantage in its excellent uniformity of the thickness of the SOI layer. In the SIMOX wafer, it is possible to form an SOI layer 0.4 μm or less in thickness and even to control the thickness of the SOI layer to 0.1 μm, or even smaller. An SOI layer 0.1 μm or less in thickness, in particular, is often used for forming a MOS-LSI for fully depletion type operation. In this case, as the thickness of the SOI layer itself is in a proportional relationship with the threshold voltage of a MOSFET, the uniformity of the thickness of the SOI layer constitutes an important quality aspect for producing devices of uniform performance at a high yield. In this regard, the SIMOX wafer having an SOI layer excellent in uniformity of the thickness has been the most promising canditate of the substrates for MOSFETs of the next generation.

A MOS-LSI formed on an SOI substrate is capable of realizing the excellent properties described above, such as the enhanced radiation resistance and latch-up resistance, the operation with low power consumption, the ultra-high-speed operation, etc., thanks to the fact that the device active area is dielectrically isolated from the substrate itself by laying the BOX layer which is an insulator between them. In this respect, the BOX layer is required to have as perfect an insulating property as possible. More concretely, it is required that the leak defects in the BOX layer (hereinafter called pinhole defects) are as small as possible and the dielectric breakdown property is as close to that of a thermally-grown oxide layer as possible.

In the production of a SIMOX wafer, oxygen ions are

implanted by applying, usually, a fixed amount of accelerating energy, typically, an accelerating voltage of 200 kV or so. It is widely known that, in the SIMOX structure formed after a high temperature heat treatment, a continuous, uniform and high quality BOX layer can be obtained only when the implantation dosing amount of the oxygen ions is 1.5×10^{18} cm^{-2} or more, or within a limited range from 2.5 to 4.5×10^{17} cm^{-2} (refer to S. Nakashima and K. Izumi, the Journal of Materials Research, Vol. 8, p.523 (1993), for example). The SIMOX wafer produced by implanting the oxygen ion amount specified above is conventionally called: a high dose SIMOX substrate when produced by implanting the oxygen ion amount in the former range; or a low dose SIMOX substrate when produced by implanting the oxygen ion amount in the latter range.

The high dose SIMOX substrate and the low dose SIMOX substrate have respective characteristics, and they are used for different applications according to the characteristics. Out of the two types of SIMOX substrates, in the case of the low dose SIMOX substrate, the dosing amount of oxygen ion implantation is comparatively small, therefore the threading dislocation density of the SOI layer is decreased, and the low dose SIMOX substrate is expected to be a technology capable of realizing low-cost production. The low dose SIMOX substrate, however, has problems such as the relatively large density of pinhole defects in the BOX layer, the high probability of dielectric breakdown property of the BOX layer becoming insufficient and so forth, because the BOX layer is thin. With regard to the BOX quality of the low dose SIMOX substrate, when it is attempted to increase the thickness of the BOX layer by simply increasing the oxygen ion implantation amount, although the pinhole defects decrease, granular substances consisted of silicon (hereinafter called silicon islands) are generated in quantities inside the BOX layer and, as

a result, the breakdown electric field of the BOX layer is lowered. However, it has been pointed out that, when the oxygen ion implantation dosing amount is decreased, in contrast, though the silicon islands decrease and the breakdown electric field of the BOX layer is improved, the density of the pinhole defects increases as the oxygen ion implantation dosing amount decreases. It has therefore been very difficult to simultaneously improve the whole quality of the BOX layer in the low dose SIMOX substrate produced according to a conventional technology.

As a technology to contribute to the quality improvement of the BOX layer of the low dose SIMOX substrate, a technology has been proposed which makes use of internal oxidation at a high temperature (internal thermal oxidation process, hereinafter called the ITOX technology in abbreviation) (Nakashima et al.: Japanese Unexamined Patent Publication No. H07-263538, or S. Nakashima et al.: the Journal of Electrochemical Society, Vol. 143, p.244). According to the ITOX technology, a thermally-grown oxide layer grows on the substrate surface through an oxidation treatment at a high temperature, and, at the same time, some amount of thermally-grown oxide layer at the upper interface of the BOX layer, and thus it becomes possible to make the BOX layer thicker. Further, it has been reported that the pinhole defects are decreased as a result, and the breakdown electric field is improved at the same time. In the ITOX technology, however, it is necessary for the surface oxide layer to grow by not less than 10 times the increase in the thickness of the BOX layer. For this reason, to secure a prescribed thickness of the SOI layer in the SIMOX structure finally obtained, it is necessary to restrict the amount of oxidation of the substrate surface. As a consequence, there has been a natural limit in the increment of the BOX layer thickness.

As a measure to make the BOX layer of a SIMOX

substrate thicker without being influenced by the above restriction, it has been proposed that, in a method wherein a series of oxygen ion implantations is conducted while changing the average depth of the implantation step-by-step or continuously and a heat treatment at a high temperature is applied thereafter, the cumulative distribution of implanted oxygen is controlled so that it falls, after the series of oxygen ion implantation, within a range in which the silicon islands are not generated, and that the distribution has a single peak so as to form a single BOX layer after the high temperature heat treatment (see Japanese Unexamined Patent Publication No. H7-201975). By this technique, it is theoretically possible to obtain a high quality BOX layer even under dosing conditions outside the so-called dose window, under which dosing conditions it is impossible to obtain a good quality BOX layer when the oxygen ion is implanted using a fixed accelerating voltage. However, it is necessary, in the proposed technique, to control the peak value of the distribution of implanted oxygen to not more than 2.25×10^{22} cm^{-3}, i.e. about a half of 4.48×10^{22} cm^{-3}, which is the oxygen concentration in silicon dioxides, in order to prevent the silicon islands from forming in the BOX layer, and, if a plurality of peaks appear in the distribution of implanted oxygen after the series of oxygen ion implantation caused by changes in process conditions or other factors, precipitation takes place during the high temperature heat treatment around each of the peaks and a single BOX layer is not formed. Because of the unstable nature of the proposed method as described above, it has a problem that precise and delicate control of the process is required in order to avoid the instability.

In the meantime, as a technology wherein oxygen ion implantation and high temperature heat treatment are repeated, a technology has been proposed wherein oxygen ion implantation at a fixed accelerating energy and high

temperature heat treatment are repeated for the purpose of improving the quality of a high dose SIMOX substrate (see Japanese Unexamined Patent Publication No. H1-17444). The object of the proposed technology is to reduce defects, such as threading dislocations, in the SOI layer finally obtained by reducing the damage generated in the substrate at each step of the implantation through dividing the implantation of a required dosing amount into a plurality of steps and recovering further from the reduced damage through applying a high temperature heat treatment after each of the implantation steps. In this technique, however, the implantation of the oxygen ion amount conventionally employed for producing a high dose SIMOX substrate is divided into several steps, and it causes no change in the thickness of the BOX layer finally obtained. Besides, it has been pointed out that, using the technique, waviness occurs conspicuously in the BOX layer formed at an intermediary step and, as a consequence, the flatness of the interface of the BOX layer finally obtained is deteriorated.

As a measure to avoid the problem, a proposal has been made, wherein the implantation is divided into two steps and a lower accelerating energy than that in the first step implantation is applied in the second step implantation, and by so doing, oxygen ions are implanted preponderantly at the interface of the BOX layer formed after the first step heat treatment and the SOI layer, and thus the flatness of the interface is improved (see Japanese Unexamined Patent Publication No. H4-249323). However, this technology is also an invention aiming at improving the quality of the high dose SIMOX substrate and, as the implantation of the total oxygen ion amount conventionally employed for producing a high dose SIMOX substrate is divided into steps, like in the previous example, it causes no change in the thickness of the BOX layer finally obtained. What is more, because the oxygen

ions are implanted in the second step on the upper side of the BOX layer already formed in the first step, the SOI layer finally obtained tends to be thin. The proposed technology is, therefore, not suitable for increasing the thickness of the BOX layer while maintaining the thickness of the SOI layer.

The object of the present invention is to provide a technology capable of increasing the thickness of the buried oxide layer of the SIMOX substrate without the above difficulties. In particular, the object of the present invention is to provide a high quality SOI substrate for a high performance LSI by making it possible to increase the thickness of the BOX layer of a SIMOX substrate produced by employing the oxygen ion implantation amount in the low dose range, keeping good quality of the BOX layer, and a method of producing the SOI substrate.

Disclosure of the Invention

In the SIMOX method wherein an SOI structure is formed by applying the implantation of oxygen ions into a single crystal silicon substrate and a heat treatment at a high temperature thereafter, the present inventors newly discovered that it is possible to increase the thickness of the BOX layer, while maintaining the thickness and crystallinity of the SOI layer and suppressing the formation of the silicon islands in the BOX layer, if, after a BOX layer is once formed through a high temperature heat treatment, oxygen ions are implanted again in a position deeper than the BOX layer thus formed and then a heat treatment at a high temperature is applied once again. The present invention, therefore, relates to a method of producing an SOI substrate which solves the above problems and, further, to the SOI substrate produced by applying the technologies of the method, and it is realized by the following means.

A method of producing a SIMOX substrate wherein a BOX layer and an SOI layer are formed by applying the implantation of oxygen ions into a silicon substrate and a heat treatment at a high temperature thereafter, characterized by: forming a BOX layer through applying a high temperature heat treatment after an oxygen ion implantation; and then, repeatedly, applying oxygen ion implantation so that the peak position of the distribution of implanted oxygen is located at a portion lower than the interface between the BOX layer, already formed, and the substrate thereunder, and a heat treatment at a high temperature thereafter.

Further, a method of producing a SIMOX substrate according to the above, characterized in that the dosing amount of an additional oxygen ion implantation does not exceed the total dosing amount of the oxygen ions implanted earlier.

Further, a method of producing a SIMOX substrate according to the above, characterized in that the accelerating energy applied to the oxygen ion implantation is different from that applied to an additional oxygen ion implantation.

Further, a method of producing a SIMOX substrate according to the above, characterized by partially removing the surface of the SOI layer already formed before the additional oxygen ion implantation.

Further, a method of producing a SIMOX substrate according to the above, characterized in that the method of removing the surface of the SOI layer is etching using a reactive substance.

Otherwise, a method of producing a SIMOX substrate according to the above, characterized in that the method of removing the surface of the SOI layer is the removal of an oxide layer after forming it by oxidizing the surface of the substrate.

Otherwise, a method of producing a SIMOX substrate according to the above, characterized in that the method

of removing the surface of the SOI layer is surface polishing.

Additionally, in the method of producing a SIMOX substrate according to the above, it is desirable that the number of repetitions of the oxygen ion implantation and the high temperature heat treatment is two.

Further, in any of the methods of producing a SIMOX substrate according to the above, it is desirable to form an oxide layer on the surface of the silicon substrate prior to the oxygen ion implantation and to remove the oxide layer after the oxygen ion implantation or the high temperature heat treatment.

Further, in the method of producing a SIMOX substrate according to the above, it is desirable that the oxygen ion implantation is conducted under a condition of an accelerating energy of 150 to 250 keV and a dosing amount of 2 to 6 x 10^{17} cm^{-2}, that an additional oxygen ion implantation is conducted under a condition of an accelerating energy of 150 to 250 keV and a dosing amount of 0.1 to 6 x 10^{17} cm^{-2}, and that the total depth of the removal of the silicon surface is 20 to 300 nm.

The present invention is, further, a SIMOX substrate produced by applying any of the methods according to the above, characterized in that the thickness of the SOI layer of the SIMOX substrate is 10 to 400 nm and the thickness of the BOX layer thereof is 60 to 250 nm.

According to the present invention, a BOX layer similar to that of a conventional low dose SIMOX substrate is once formed through an oxygen ion implantation and a high temperature heat treatment. For this reason, when the oxygen implanted at an additional oxygen ion implantation precipitates during the subsequent high temperature heat treatment, the precipitation takes place stably, because the BOX layer already formed exists and the precipitating oxygen is absorbed in the BOX layer. As a result, it is possible to obtain a single BOX layer stably. In addition, by the

present invention, it is also possible to increase the thickness of the BOX layer and, at the same time, reduce the density of the pinhole defects in the BOX layer.

Brief Description of the Drawings

Fig. 1 shows the production processes 1) and 2) of a SIMOX substrate according to a conventional technology and schematic sectional illustrations of silicon substrates at the production processes and the distributions of oxygen concentration in the silicon substrates.

Fig. 2 shows the production processes 3) and 4) of a SIMOX substrate according to the first embodiment of the present invention and schematic sectional illustrations of silicon substrates at the production processes and the distributions of oxygen concentration in the silicon substrates.

Fig. 3 shows the production processes 3), 4) and 5) of a SIMOX substrate according to the second embodiment of the present invention and schematic sectional illustrations of silicon substrates at the production processes and the distributions of oxygen concentration in the silicon substrates.

Fig. 4 shows the production processes 3), 4), 5) and 6) of a SIMOX substrate according to the third embodiment of the present invention and schematic sectional illustrations of silicon substrates at the production processes and the distributions of oxygen concentration in the silicon substrates.

Fig. 5 is a graph showing the density of the pinhole defects in the BOX layer, comparing the first to third examples of the present invention, a conventional example and a comparative example.

Fig. 6 is a graph showing the breakdown electric field of the BOX layer, comparing the first to third examples of the present invention, a conventional example and a comparative example.

Fig. 7 is a graph showing the density of defects in the SOI layer, comparing the first to third examples of the present invention, a conventional example and a comparative example.

Best Mode for Carrying Out the Invention

Preferable embodiments of the present invention are explained hereafter based on the schematic sectional illustrations in Figs. 1 to 4.

The first half of the processes to produce a SIMOX substrate according to an embodiment of the present invention employs the production processes of the SIMOX substrate according to a conventional technology shown in Fig. 1. In the processes shown in Fig. 1, 1) an oxygen implanted zone 2' is formed by charging a single crystal silicon substrate 1 into an ion implantation apparatus and implanting oxygen ions up to a prescribed dosing amount in the surface of the substrate, while heating the substrate so as to maintain its crystallinity. Then, the substrate is discharged from the ion implantation apparatus and, 2) a SIMOX structure having an SOI layer 3' and a BOX layer 4' is formed by applying a high temperature heat treatment in a heat treatment furnace. It has to be noted that, when forming a SIMOX substrate in a low dose range by applying, for instance, an accelerating voltage of 150 to 250 kV for the oxygen ion implantation, it is desirable, to obtain a high quality BOX layer, to apply a dosing amount of 2 to 6 x 10^{17} cm^{-2} as the prescribed dosing amount. The oxygen ion implantation and the high temperature heat treatment described above are called the first oxygen ion implantation and the first high temperature heat treatment, respectively, in the explanations of this description.

In the first embodiment of the present invention shown in Fig. 2, after completing the processes shown in Fig. 1, the substrate is charged into the ion

implantation apparatus again, and 3) an oxygen ion implanted zone 2 is formed by applying oxygen ion implantation under such an accelerating voltage that the peak of the distribution of the implanted oxygen ions is located at the lower portion of the already formed BOX layer 4'. After that, the substrate is discharged from the ion implantation apparatus and, then, 4) a SIMOX structure having an SOI layer 3 and a BOX layer 4 is formed by applying a high temperature heat treatment in a heat treatment furnace. The oxygen ion implantation and the high temperature heat treatment described above are called the second oxygen ion implantation and the second high temperature heat treatment, respectively, in the explanations of this description.

By the method shown in Fig. 2, the oxygen ions implanted at the second oxygen ion implantation aggregate onto the already formed BOX layer 4' from the lower side during the subsequent second high temperature heat treatment. In order to realize the stable aggregation of the oxygen ions in the above process, it is desirable to control the dosing amount of the oxygen ions of the second oxygen ion implantation so as not to exceed that of the first oxygen ion implantation. By so doing, the precipitation of the oxygen ions proceeds during the second high temperature heat treatment so that the oxygen ions implanted at the second oxygen ion implantation aggregate in priority to the BOX layer 4' already formed, without precipitating them independently. What is more, as the precipitation process from the second oxygen ion implantation to the second high temperature heat treatment hardly affects the upper interface of the BOX layer 4', as a result, the BOX layer 4 is made thicker, maintaining good uniformity of the thickness of the SOI layer.

As is well known, the damage inflicted on the material wherein ions are implanted by the implanted ions becomes larger as the ions lose their energy and

decelerate in the material wherein ions are implanted. The degree of the damage inflicted on the material wherein ions are implanted by the implanted ions, therefore, becomes large at the vicinity immediately above the position where the ions halt. By the method shown in Fig. 2, it is possible to concentrate the damage generated in a substrate by the second ion implantation on the inside or lower portion of the BOX layer 4' formed during the first high temperature heat treatment. For this reason, it is possible to suppress the new damage to the already formed SOI layer 3' generated by the second oxygen ion implantation and, as a result, to suppress the generation of defects such as threading dislocations in the SOI layer 3 formed after the second high temperature heat treatment.

In the second embodiment of the present invention shown in Fig. 3, after completing the processes shown in Fig. 1, 3) the SOI layer 3' is made thinner by removing a part of its surface. Then, the substrate is charged into the ion implantation apparatus again and 4) oxygen ion implantation is carried out by applying such an accelerating voltage that the peak of the distribution of implanted oxygen ions is located at the lower portion of the already formed BOX layer 4' as shown in Fig. 2. Thereafter, the substrate is discharged from the ion implantation apparatus and, then, a SIMOX structure having an SOI layer 3 and a BOX layer 4 is formed by applying a high temperature heat treatment in a heat treatment furnace.

By the method shown in Fig. 3, it is possible to implant oxygen ions in a desired position without changing the accelerating voltage used in the second oxygen ion implantation so much from the accelerating voltage used in the first oxygen ion implantation, comparing with the method shown in Fig. 2. As a consequence, the freedom in the combination of the accelerating voltage used in the second oxygen ion

implantation expands within the capacity range of the ion implantation apparatus employed and, for this reason, it becomes possible to expand the freedom in the thicknesses of the SOI and BOX layers finally formed. At the same time, the load imposed on the ion implantation apparatus by the change of operating conditions is alleviated. Note that techniques such as reactive ion etching, etching using a mixed solution of hydrofluoric acid and nitrous acid, mechanical polishing, etc. can be used as the method of removing a part of the SOI layer surface before applying the second oxygen ion implantation.

In the third embodiment of the present invention shown in Fig. 4, after completing the processes shown in Fig. 1, 3) a thermally-grown oxide layer 5 is formed on the surface of the SOI layer 3', and then 4) the oxide layer is removed. A solvent to selectively dissolve the oxide layer or the like may be used for the removal. Subsequently, a SIMOX structure having an SOI layer 3 and a BOX layer 4 is formed by applying 5) an ion implantation in the same manner as in Fig. 2 and 6) a heat treatment. By this method, too, the same effects as those explained in the description of the second embodiment are expected to show.

It has to be noted that, in the first to third embodiments of the present invention shown in Figs. 2 to 4, respectively, it is acceptable to form an oxide layer on the surface of a silicon substrate prior to the first oxygen ion implantation and to remove the oxide layer using a solvent as described above after the first oxygen ion implantation or the first high temperature heat treatment immediately thereafter. In order that the oxide layer formed on the substrate surface is not erased by the sputtering during the oxygen ion implantation in the above case, it is desirable to form the oxide layer in a thickness of 30 nm or more. In order to obtain the SOI layer after the high temperature heat treatment, on the other hand, it is necessary to restrict the thickness

of the surface oxide layer to 400 nm or so at the largest.

The first to third embodiments of the present invention shown in Figs. 2 to 4, respectively, are examples wherein the oxygen ion implantation is repeated twice in total, but the partial removal of the SOI layer and the subsequent oxygen ion implantation and high temperature heat treatment may be repeated as long as the SOI layer does not disappear. When an accelerating voltage of 150 to 250 kV and a dosing amount of 2 to 6 x 10^{17} cm^{-2} are applied to the oxygen ion implantation, as explained earlier, it is desirable that the total removal depth of the surface of the SOI layer or the surface of the silicon single crystal is 20 nm or more in order to obtain the effects of the present invention, and 300 nm or less in order to prevent the SOI layer from disappearing. In this case, it is possible to form the finally obtained SOI layer in any desired thickness up to an upper limit of 400 nm or so, as long as it is within a range not letting the SOI layer disappear, by appropriately controlling process conditions.

In the first to third embodiments of the present invention shown in Figs. 2 to 4, respectively, the quality of the BOX layer is also improved with respect to the pinhole defects, the breakdown electric field and so forth, as the thickness of the BOX layer increases. The extent of the quality improvement becomes greater as the total of the dosing amounts at the second and subsequent oxygen ion implantation processes increases and, to obtain tangible improvement effects with respect to these quality aspects of the BOX layer, it is desirable that the total of the dosing amounts at the second and subsequent oxygen ion implantation processes is at least 0.1 x 10^{17} cm^{-2} or more, more preferably, 0.5 x 10^{17} cm^{-2} or more.

With regard to an apparatus used for applying the oxygen ion implantation according to the present

invention, any apparatus is acceptable as long as it is capable of accelerating oxygen ions by applying a voltage and thus implanting them into a silicon wafer through the surface, and there are no specific restrictions as to its type, ion implanting method, etc.

With regard to the conditions of the first oxygen ion implantation in the production of the SIMOX substrate according to the present invention, the conditions in the low dose range are already shown. However, the conditions of the first oxygen ion implantation are not necessarily limited to those of the low dose range, and the conditions of the so-called middle dose or high dose range where the dosing amount is larger than those shown above may be applied. For the purpose of improving the BOX layer quality, such as its thickness, pinhole defects, breakdown electric field, and so forth, however, greater effects are expected when the present invention is applied to the cases where the conditions of the low dose range are used and much improvement in the quality is required. It is also acceptable to divide each of the first oxygen ion implantation and the second and subsequent oxygen ion implantation into two or more steps. For the purpose of reducing the crystal defects in the SOI layer, it is desirable that the temperature of the substrate at least during the first oxygen ion implantation is 500 to 600°C or so.

With regard to an apparatus used for a high temperature heat treatment, there is no specific restriction as long as the apparatus is capable of carrying out a heat treatment at a desired temperature for a desired period of time. Typically, a high temperature heat treatment furnace can be named as a desirable apparatus for the purpose. A lamp anneal furnace can also be applied, as long as it satisfies required performances in terms of treatment temperature, time, etc. The conditions of a heat treatment furnace other than the treatment temperature and time, such as

charging temperature, heating rate, cooling rate, and so forth are not limited specifically, and the heating or cooling may be conducted in two or more steps.

With regard to the conditions of a high temperature heat treatment, it is desirable, for removing the damage caused by the ion implantation and obtaining a high quality SOI structure, to conduct the heat treatment at a temperature of 1,300°C or higher but below the melting point of silicon. However, the heat treatment temperature is not limited to the above temperature range. A non-oxidizing atmosphere using an inert gas or an atmosphere containing a small amount of oxygen added to the non-oxidizing atmosphere is desirable as the atmosphere of the heat treatment for removing the damage. However, it is not necessarily limited to those atmospheres, and an oxidizing atmosphere is also acceptable. Argon, nitrogen, and the like are used, typically, as the inert gas. However, it is not necessarily limited to them. Further, a high temperature oxidizing treatment may be applied subsequent to the high temperature heat treatment.

Example

Examples of the present invention are explained hereafter based on the schematic sectional illustrations in Figs. 1 to 4.

Oxygen ions were implanted in the surface of p-type (100) silicon substrates at an accelerating voltage of 180 kV and up to an implantation amount of 4×10^{17} cm^{-2}, according to the processes shown in Fig. 1. The temperature of the substrates during the ion implantation was set at 600°C for the purpose of maintaining their crystallinity. Then, the substrates were discharged from the ion implantation apparatus and subjected to a heat treatment at a temperature of 1,300°C or higher for 6 h. in a heat treatment furnace to form the SIMOX structure. The heat treatment was conducted in an atmosphere of

argon mixed with 1% of or less of oxygen. The structure of the substrate discharged from the furnace was evaluated by spectroscopic-ellipsometry and, as a result, the SOI layer measured roughly 340 nm in thickness, and the BOX layer was 85 nm thick.

In the first example according to the first embodiment of the present invention shown in Fig. 2, after completing the processes shown in Fig. 1, the substrate was charged into the ion implantation apparatus once again and subjected to another oxygen ion implantation process at an accelerating voltage of 210 kV and up to an implantation amount of 2×10^{17} cm^{-2}. The temperature of the substrate during the ion implantation was set, like in the first implantation, at 600°C. Then, the substrate was discharged from the ion implantation apparatus and subjected to a heat treatment process at a temperature of 1,300°C or higher for 6 h. in an atmosphere of argon mixed with 1% of or less of oxygen in the heat treatment furnace. After the heat treatment, the substrate discharged from the furnace was evaluated, as described earlier, by spectroscopic-ellipsometry. As a result, the SOI layer measured roughly 280 nm in thickness, and the BOX layer 130 nm.

In the second example according to the second embodiment of the present invention shown in Fig. 3, after completing the processes shown in Fig. 1, the surface of an SOI layer was etched with a mixed solution of hydrofluoric acid and nitrous acid up to a depth of about 120 nm to obtain an SOI layer roughly 200 nm in thickness. Then, the substrate was charged into the ion implantation apparatus once again and subjected to an oxygen ion implantation process at an accelerating voltage of 190 kV and up to an implantation amount of 2×10^{17} cm^{-2}. The temperature of the substrate during the ion implantation was set, as in the first implantation, at 600°C. Then, the substrate was discharged from the ion implantation apparatus and subjected to a heat

treatment at a temperature of 1,300°C or higher for 6 h. in an atmosphere of argon mixed with 1% of or less of oxygen in the heat treatment furnace. After the heat treatment, the substrate discharged from the furnace was evaluated, as described earlier, by spectroscopic-ellipsometry. As a result, the SOI layer measured roughly 160 nm in thickness, and the BOX layer 130 nm.

In the third example according to the third embodiment of the present invention shown in Fig. 4, after completing the processes shown in Fig. 1, a thermally-grown oxide layer roughly 270 nm in thickness was formed on a surface of an SOI layer at a temperature of 1,000°C or higher and, then, the oxide layer was removed using a solution of hydrofluoric acid. As a result, a part of the SOI layer about 220 nm in thickness remained on the substrate. The ion implantation and heat treatment were conducted subsequently under the same conditions as in the second example. The SOI layer and BOX layer finally obtained were about 160 nm and 130 nm in thickness, respectively.

The quality of the BOX layers of the samples thus obtained was evaluated and compared. Besides the samples of the above three examples, also evaluated were a sample of a conventional example produced through the processes shown in Fig. 1 and a sample of a comparative example produced through the processes shown in Fig. 1 such that the oxygen ion implantation amount was 6×10^{17} cm^{-2}, which was the same amount as the total implantation amount of the examples according to the present invention.

The pinhole defects in the BOX layer were evaluated by the copper plating method, wherein: each of the samples was arranged so that only the top surface of the substrate touched an electrolyte containing copper ions and the bottom surface of the substrate touched a cathode, and an anode was placed in the electrolyte; then, copper plated portions were made to form on the top

surface of the substrate immediately above the portions where pinholes existed in the BOX layer, by applying to the anode and cathode a low voltage of about 10 V which would not destroy the BOX layer; and the density of the pinholes in the BOX layers was evaluated by counting the number of the copper plated portions. Fig. 5 shows the pinhole density in each of the samples of the conventional example, the first to third examples of the present invention and the comparative example. It was made clear that, in the samples of the first to third examples and the comparative example, the pinhole density was reduced to about one fifth that of the sample of the conventional example, and that the number of pinholes decreased as the total amount of the oxygen implantation increased.

In succession, the breakdown electric field of the BOX layer of each sample was evaluated, wherein: the SOI layer of each sample was divided into sections 1 mm^2 each by lithography and etching and an Al electrode was formed on the top surface of each of the sections by vacuum deposition; an Au film was formed on the bottom surface of each sample substrate as the other electrode by vacuum deposition; and the breakdown electric field of the BOX layer was evaluated by applying a voltage to the Al electrodes and the Au electrode on the bottom surface of each substrate, thus imposing an electric field on the BOX layer, and measuring the current flowing at the time. Here, the electric field strength was calculated by dividing the voltage imposed on both electrodes by the thickness of the BOX layer.

Fig. 6 shows the breakdown electric field of the BOX layer in each of the samples of the conventional example, the first to third examples and the comparative example. It is clear in the figure that, in the samples of the first to third examples, the breakdown electric field of the BOX layer is higher than that in the conventional example. It was found out, on the other hand, that, in

the sample of the comparative example produced with the same dosing amount as in the first to third examples, the dielectric breakdown characteristic of the BOX layer was inferior to that of the sample of the conventional example. This is presumably because the number of the silicon islands in the BOX layer was increased by simply increasing the dosing amount of the oxygen ions and, as a result, the breakdown electric field decreased, contrary to expectation.

Fig. 7 shows the density of defects evaluated in terms of etch pit in the SOI layer of each sample. It is clear from the figure that, in the samples of the first to third examples, the defect density is kept at the same level as in the conventional example, despite the fact that they underwent additional ion implantation. The figure also shows that, in the sample of the comparative example, to which the same amount of oxygen ions as in the samples of the first to third examples was implanted in one step, in contrast, the defect density of the SOI layer is higher by more than 10%, which indicates that the damage increases as the amount of the implanted ions increases. This result can be interpreted as follows: in the first to third examples, the oxygen ions were implanted at the second oxygen ion implantation in the lower side of the BOX layer formed through the first heat treatment and, for this reason, most of the damage generated at the second implantation was introduced to the inside or the lower side of the BOX layer and, as a consequence, the influence of defect formation on the finally formed SOI layer was alleviated.

Summarizing the above results, it is clear that, in the first to third examples according to the present invention, the increase of the defects in the SOI layer is suppressed in spite of the increase in the oxygen ion implantation amount, while the thickness of the BOX layer is increased, the number of pinholes in the BOX layer is decreased and the breakdown electric field is raised,

compared with the conventional example.

Industrial Applicability

As is explained above, the present invention makes it possible, in the production of a SIMOX substrate, to obtain a high quality BOX layer whose thickness is heavier than that of a SIMOX substrate produced by a conventional method, by applying to a SIMOX substrate produced by a conventional method additional oxygen implantation so that the peak position of the distribution of implanted oxygen is located at the portion lower than the interface between the BOX layer already formed and the substrate thereunder and, then, a high temperature heat treatment.

CLAIMS

1. A method of producing a SIMOX substrate wherein a buried oxide layer and a surface silicon layer are formed by applying the implantation of oxygen ions in a silicon substrate and a high temperature heat treatment thereafter, characterized by: forming the buried oxide layer through applying a high temperature heat treatment after an oxygen ion implantation; then applying an additional oxygen ion implantation so that the peak position of the distribution of implanted oxygen is located at a portion lower than the interface between the buried oxide layer, already formed, and the substrate thereunder; and then applying another high temperature heat treatment.

2. A method of producing a SIMOX substrate wherein a buried oxide layer and a surface silicon layer are formed by applying the implantation of oxygen ions in a silicon substrate and a high temperature heat treatment thereafter, characterized by: forming the buried oxide layer through applying a high temperature heat treatment after an oxygen ion implantation; then applying an additional oxygen ion implantation so that the dosing amount of the additional oxygen ion implantation does not exceed the total dosing amount of the oxygen ions implanted earlier and that the peak position of the distribution of implanted oxygen is located at a portion lower than the interface between the buried oxide layer, already formed, and the substrate thereunder; and then applying another high temperature heat treatment.

3. A method of producing a SIMOX substrate wherein a buried oxide layer and a surface silicon layer are formed by applying the implantation of oxygen ions in a silicon substrate and a high temperature heat treatment thereafter, characterized by: forming the buried oxide layer through applying a high temperature heat treatment after an oxygen ion implantation; then applying an additional oxygen ion implantation so that the

accelerating energy formerly applied to the oxygen ion implantation is different from that applied to the additional oxygen ion implantation and that the peak position of the distribution of implanted oxygen is located at a portion lower than the interface between the buried oxide layer, already formed, and the substrate thereunder; and then applying another high temperature heat treatment.

4. A method of producing a SIMOX substrate wherein a buried oxide layer and a surface silicon layer are formed by applying the implantation of oxygen ions in a silicon substrate and a high temperature heat treatment thereafter, characterized by: forming the buried oxide layer through applying a high temperature heat treatment after an oxygen ion implantation; then applying an additional oxygen ion implantation so that the dosing amount of the additional oxygen ion implantation does not exceed the total dosing amount of the oxygen ions implanted earlier, that the accelerating energy formerly applied to the oxygen ion implantation is different from that applied to the additional oxygen ion implantation and that the peak position of the distribution of implanted oxygen is located at a portion lower than the interface between the buried oxide layer, already formed, and the substrate thereunder; and then applying another high temperature heat treatment.

5. A method of producing a SIMOX substrate wherein a buried oxide layer and a surface silicon layer are formed by applying the implantation of oxygen ions in a silicon substrate and a high temperature heat treatment thereafter, characterized by: forming the buried oxide layer through applying a high temperature heat treatment after an oxygen ion implantation; then partially removing the surface of the surface silicon layer already formed; then applying an additional oxygen ion implantation so that the peak position of the distribution of implanted oxygen is located at a portion lower than the interface

between the buried oxide layer, already formed, and the substrate thereunder; and then applying another high temperature heat treatment.

6. A method of producing a SIMOX substrate wherein a buried oxide layer and a surface silicon layer are formed by applying the implantation of oxygen ions in a silicon substrate and a high temperature heat treatment thereafter, characterized by: forming the buried oxide layer through applying a high temperature heat treatment after an oxygen ion implantation; then partially removing the surface of the surface silicon layer already formed; then applying an additional oxygen ion implantation so that the dosing amount of the additional oxygen ion implantation does not exceed the total dosing amount of the oxygen ions implanted earlier and that the peak position of the distribution of implanted oxygen is located at a portion lower than the interface between the buried oxide layer, already formed, and the substrate thereunder; and then applying another high temperature heat treatment.

7. A method of producing a SIMOX substrate wherein a buried oxide layer and a surface silicon layer are formed by applying the implantation of oxygen ions in a silicon substrate and a high temperature heat treatment thereafter, characterized by: forming the buried oxide layer through applying a high temperature heat treatment after an oxygen ion implantation; then partially removing the surface of the surface silicon layer already formed; then applying an additional oxygen ion implantation so that the accelerating energy formerly applied to the oxygen ion implantation is different from that applied to the additional oxygen ion implantation and that the peak position of the distribution of implanted oxygen is located at a portion lower than the interface between the buried oxide layer, already formed, and the substrate thereunder; and then applying another high temperature heat treatment.

8. A method of producing a SIMOX substrate wherein a buried oxide layer and a surface silicon layer are formed by applying the implantation of oxygen ions in a silicon substrate and a high temperature heat treatment thereafter, characterized by: forming the buried oxide layer through applying a high temperature heat treatment after an oxygen ion implantation; then partially removing the surface of the surface silicon layer already formed; then applying an additional oxygen ion implantation so that the dosing amount of the additional oxygen ion implantation does not exceed the total dosing amount of the oxygen ions implanted earlier, that the accelerating energy formerly applied to the oxygen ion implantation is different from that applied to the additional oxygen ion implantation and that the peak position of the distribution of implanted oxygen is located at a portion lower than the interface between the buried oxide layer, already formed, and the substrate thereunder; and then applying another high temperature heat treatment.

9. A method of producing a SIMOX substrate according to claim 5, characterized in that the method of removing the surface of the surface silicon layer is any one of etching using a reactive substance, the removal of an oxide layer after forming it by oxidizing the silicon at the surface of the substrate, and surface polishing.

10. A method of producing a SIMOX substrate according to claim 6, characterized in that the method of removing the surface of the surface silicon layer is any one of etching using a reactive substance, the removal of an oxide layer after forming it by oxidizing the silicon at the surface of the substrate, and surface polishing.

11. A method of producing a SIMOX substrate according to claim 7, characterized in that the method of removing the surface of the surface silicon layer is any one of etching using a reactive substance, the removal of an oxide layer after forming it by oxidizing the silicon at the surface of the substrate, and surface polishing.

12. A method of producing a SIMOX substrate according to claim 8, characterized in that the method of removing the surface of the surface silicon layer is any one of etching using a reactive substance, the removal of an oxide layer after forming it by oxidizing the silicon at the surface of the substrate, and surface polishing.

13. A SIMOX substrate produced by the production method according to any one of claims 1 to 12, characterized in that the thickness of the surface silicon layer of the SIMOX substrate is 10 to 400 nm, and the thickness of the buried oxide layer thereof is 60 to 250 nm.