

**PROCESS FOR THE MANUFACTURE OF A SEMICONDUCTOR ELEMENT
COMPRISING A LAYER FOR TRAPPING CHARGES**

FIELD OF THE INVENTION

The invention relates to a process for manufacturing a semiconductor element comprising a layer for trapping charges.

TECHNOLOGICAL BACKGROUND OF THE INVENTION

Integrated devices are normally prepared on substrates in the form of wafers, which act mainly as support in their manufacture. However, the increase in the degree of integration and in the performances expected for these devices is leading to an increasingly significant coupling between their performances and the characteristics of the substrate on which they are formed. This is particularly the case with radiofrequency (RF) devices, which process signals for which the frequency is between approximately 3 kHz and 300 GHz, which in particular have application in the field of telecommunications (telephony, Wi-Fi, Bluetooth, and the like).

As example of the device/substrate coupling, electromagnetic fields, which result from the high frequency signals propagating in the devices, penetrate into the depth of the substrate and interact with the possible charge carriers which are found therein. This results in an unnecessary consumption of a portion of the energy of the signal by insertion loss and possible influences between components by crosstalk.

Radiofrequency devices, such as switches and aerial tuners, and also power amplifiers, can be prepared on substrates specifically adapted in order to take into account these phenomena and in order to improve the performances thereof.

Thus, silicon on insulator (SOI) substrates are known which comprise, as is represented in Figure 1, a support substrate 2, a charge-trapping layer 3 positioned on the support substrate 2, an insulating layer 4 positioned on the trapping layer 3, and a surface silicon layer 5 positioned on the insulating layer. The support substrate 2 can exhibit a resistivity of greater than 1 kohm.cm. The trapping layer 3 can comprise nondoped polycrystalline silicon. The charge-trapping layer 3 makes it possible to reduce the abovementioned device/substrate coupling and thus to ensure good performances for the RF devices. The manufacture of this type of substrate is described, for example, in the documents FR 2 860 341, FR 2 933 233, FR 2 953 640 and US 2015115480.

The Applicant Company has observed that the application of a rapid heat treatment applied to such an SOI substrate could result in the radiofrequency properties of this substrate being affected. In point of fact, these rapid heat treatments are of particular use in treating the surface of a substrate during its manufacture. This is also a necessary stage in the normal processes for the manufacture of CMOS components, for example for the activation of the dopants.

More specifically, the Applicant Company has observed that the "second harmonic distortion" characterization measurement proves to be of the order of 25% lower in the case of a substrate which has been subjected to a rapid heat treatment than in the case of a substrate which has not been subjected to it.

This characterization measurement, a detailed description of which will be found in the document entitled "White paper - RF SOI Characterisation" of January 2015 and published by Soitec, is particularly relevant as it is very representative of the expected performance of an RF device formed on the substrate characterized.

However, the level achieved by this measurement on the SOI substrates exhibiting a charge-trapping layer and which have been subjected to a rapid heat treatment is not sufficiently high to guarantee the operation of the RF device under the specifications required.

OBJECT OF THE INVENTION

Embodiments of the invention seek to provide a process for the manufacture of a semiconductor element comprising a rapid heat treatment stage which does not exhibit the losses in performances found.

BRIEF DESCRIPTION OF THE INVENTION

For the purpose of the achieving of this aim, an aspect of the invention provides, as it is most broadly accepted, a process for the manufacture of a semiconductor element, the process comprising a stage of rapid heat treatment of a substrate comprising a charge-trapping layer which is capable of damaging an RF characteristic of this substrate.

This process is noteworthy in that the rapid heat treatment stage is followed by a healing heat treatment of the substrate between 700°C and 1100°C for a period of time of at least 15 seconds.

Surprisingly, the Applicant Company has demonstrated that, following this healing heat treatment, the substrate exhibits the expected radiofrequency characteristic, that is to say at the same level as a substrate which was not treated by a rapid heat treatment.

The healing heat treatment is simple to carry out; it can be a heat treatment at 950°C over one hour in a neutral or

reducing atmosphere carried out in a conventional vertical oven.

Advantageously, the radiofrequency characteristic of the substrate is evaluated by a second harmonic distortion measurement. As was indicated above, this measurement is very representative of the RF performance of a component which will be formed on this substrate.

Preferably, the rapid heat treatment is carried out in a rapid heat treatment device, such as a rapid thermal annealing (RTA) device or in a flash annealing device, which are commonly used in the fields of the manufacture of semiconductor components and substrates.

Advantageously, the rapid heat treatment comprises the exposure of the substrate to a treatment atmosphere for a maximum period of time of two minutes at a plateau temperature of between 1125 and 1250°C. These treatment conditions are particularly effective for the manufacture of a substrate or of a component. The healing heat treatment, which makes it possible in the end to completely or partially recover the expected radiofrequency performance of the element, does not consist in choosing weakened rapid heat treatment conditions which would be targeted at limiting their impact on the RF characteristic of the substrate.

The semiconductor element can be a substrate, for example a silicon on insulator (SOI) substrate, comprising a charge-trapping layer as was presented in the preamble, or a semiconductor device manufactured on this substrate. This is because, particularly advantageously, the healing heat treatment according to the invention is particularly versatile and can be applied either during the manufacture of a substrate or during the manufacture of a component on this substrate.

Preferably, the healing heat treatment is carried out in situ in the rapid heat treatment device. The use of an additional device is thus avoided and the process for the manufacture of the element is simplified.

Very advantageously, the healing heat treatment is carried out by controlling the rapid fall in temperature of the device at less than 40°C per second.

The healing heat treatment according to the invention is of particular use when the substrate is a wafer with a diameter of at least 200 mm. This is because it is difficult, for these wafer sizes, to envisage managing without a rapid heat treatment for the manufacture of the substrates, the specifications of which are very strict. This is because the known alternative means (chemical-mechanical polishing, long annealing) do not make it possible to uniformly treat the wafer over the whole of its surface during a short treatment time.

Preferably, the charge-trapping layer is a polysilicon layer.

BRIEF DESCRIPTION OF THE DRAWINGS

A better understanding of the invention will be obtained in the light of the description which follows of the nonlimiting embodiments of the invention, with reference to the appended figures, among which:

- Figure 1 represents a substrate exhibiting a charge-trapping layer of the state of the art;
- Figure 2 represents the sequence of stages of a process for the manufacture in accordance with the invention of a semiconductor element;
- Figure 3 represents a known configuration of a rapid thermal annealing device;

- Figure 4 reproduces the temperature profile of a rapid heat treatment in a rapid thermal annealing device;
- Figure 5 represents an example of healing heat treatment according to an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Figure 2 represents the sequence of stages composing a process for the manufacture of a semiconductor element in accordance with the invention.

The term "semiconductor elements" denotes without distinction a semiconductor substrate or device, in particular for applications in the RF field. The invention is thus applicable to the manufacture of one or other of these elements.

During a first stage, a substrate 1 comprising a charge-trapping layer 3 is provided.

Preferably, this substrate 1 is a silicon on insulator (SOI) substrate exhibiting a surface silicon layer 5, an insulating layer 4, for example made of silicon oxide, and a support 2. The charge-trapping layer 3 is positioned between the insulating layer 4 and the support 2.

As is documented in the documents forming the state of the art presented in the preamble, the substrate 1 can be prepared in multiple ways. However, preferably, the latter is manufactured by application of Smart Cut™ technology, according to which a silicon oxide layer intended to form the surface silicon layer 5 and the insulating layer 4 of the substrate 1 is transferred to a support 2 provided with the trapping layer 3. This transfer stage is conventionally followed by a sequence of finishing the substrate 1 in order to confer the required properties on it, in particular as regards its surface state.

In the context of the present invention, the support 2 preferably exhibits characteristics of high resistivity, of greater than 1 kohm.cm. It can correspond to a silicon substrate of p type exhibiting a low amount of interstitial oxygen (denoted by the expression "Low Oi") of between 6 and 10 ppm.

It can also be a silicon substrate exhibiting a high amount of interstitial oxygen (denoted by the expression "High Oi") of greater than 26 ppm.

Under certain circumstances, in particular when the trapping layer 3 exhibits a thickness which is sufficient and greater than 30 microns, the support 2 can exhibit a standard resistivity, of less than 1 kohm.cm.

Conventionally, the substrate 1 can be provided in the form of a circular wafer, the diameter of which can be 200, 300 or indeed even 450 mm.

The trapping layer 3 can be of highly varied nature, as is reported in the documents forming the state of the art. Generally, it is a noncrystalline layer exhibiting structural defects, such as dislocations, grain boundaries, amorphous regions, interstices, inclusions, pores, and the like.

These structural defects form traps for the charges liable to move through the material, for example at incomplete or pendant chemical bonds. Conduction in the trapping layer is thus prevented, which layer consequently exhibits a high resistivity.

Advantageously, and for reasons of simplicity of use, this trapping layer 3 is formed of a polycrystalline silicon layer. Its thickness, in particular when it is formed on a resistive support, can be between 1 and 3 μm . However, other thicknesses

of less than or greater than this interval can be fully envisaged.

The trapping layer 3 made of polycrystalline silicon can be formed by deposition on the support 4 from a gaseous silicon source, such as dichlorosilane or trichlorosilane, as is well known per se. In order to maintain the polycrystalline quality of this layer during the heat treatments to which the substrate 1 may be subjected, an amorphous layer, made of silicon dioxide for example, can advantageously be provided on the support substrate 2 before the deposition of the charge-trapping layer 3.

In a following stage of a process in accordance with the invention, and always in connection with Figure 2, a rapid heat treatment is applied to the substrate 1.

This rapid heat treatment stage can form part of the finishing sequence of the substrate 1 during its manufacture. It can also correspond to a stage of manufacture of a semiconductor device, for example a stage of activation of dopants.

The term "rapid heat treatment" denotes a stage during which the substrate 1 is exposed to a treatment atmosphere for a maximum duration of two minutes at a plateau treatment temperature. The plateau treatment temperature is typically between 1125 and 1250 degrees. The phases of rise and fall in the plateau temperature are carried out at a high heat gradient of more than 60°C/s, which makes it possible to limit the total duration of the treatment.

The duration of the treatment plateau, according to the rapid heat treatment device chosen, can be very short, of the order of a few microseconds in a flash annealing device, or

can extend to a duration of 15 to 45 seconds in a rapid annealing oven.

The treatment atmosphere depends on the purpose of this treatment. It can, for example, be a neutral, reducing or oxidizing atmosphere.

In order to apply this rapid heat treatment, there is known, for example, and as is represented diagrammatically in Figure 3, a rapid thermal annealing device comprising a quartz chamber 6 for receiving a substrate to be treated. The treatment is carried out using heating lamps 7 positioned below and above the substrate. During the treatment, the substrate is kept horizontal in the chamber on a support formed of three points 8. The atmosphere of the chamber can be controlled by introducing therein a chosen gas, which can be discharged via an exhaust system 9, the opening of which is controllable.

The rapid heat treatment is applied using this device by providing electric power to the lamps 7 in order to heat the substrate by radiation up to a predetermined temperature, for example between 1150°C and 1250°C. The rise in temperature of the substrate is very rapid, of the order of 60°C per second or more, with the result that from 10 to 20 seconds are necessary to reach the plateau temperature. The heat treatment is carried out at this plateau temperature for a period of time which can reach, in this device, from 30 seconds to two minutes. At the end of this period, the electric power provided to the lamps 7 is interrupted and the temperature of the substrate falls very rapidly, of the order also of 60°C per second. Generally from 20 to 30 seconds are necessary to carry out the cooling of the substrate and to allow it to be extracted from the chamber. A typical temperature profile obtained in this device is, for example, reproduced in Figure 4. It should be noted that the pyrometer which equips the chamber 6 and which makes possible temperature measurement is active only for temperature values of greater than

approximately 600°C to 700°C, which explains the truncated shape of the plotting of Figure 4.

On conclusion of this rapid heat treatment, it was observed, entirely surprisingly, that certain RF characteristics of the substrate 1 had deteriorated. This is in particular the case with the second harmonic distortion measurement, mention of which was made in the introduction of the present patent application.

Without committing the present invention to any one physical interpretation of these results and of the phenomena which might be involved, it appears that the trapping layer 3 is particularly sensitive to the rapid heat treatment. The structural defects or the electrochemical bonds appear to reorganize under the effect of the temperature and/or of the temperature gradients. Additionally, the specific profile of the rapid heat treatment may favour the generation in excess of charge carriers saturating the trapping properties of the layer 3.

Whatever the origin thereof, the observation of a worsened radiofrequency characteristic of the substrate 1 does not make it possible to guarantee the operation of a semiconductor device within the specifications required on the substrate 1.

On referring again to Figure 2, the invention provides for the rapid heat treatment stage to be followed by a healing heat treatment of the substrate 1 in order to at least partially recover the measured losses in performances.

Particularly surprisingly, a healing heat treatment of between 700 and 1100°C for a period of time of 15 seconds at least appears sufficient for the substrate 1 to exhibit an improved radiofrequency characteristic. The healing heat treatment atmosphere can consist of a neutral gas, such as argon, of a reducing gas, such as hydrogen, or even of a mixture of these two gas types. It can, for example, be

hydrogen-comprising nitrogen approximately 95 per cent composed of nitrogen and 5 per cent composed of hydrogen, often denoted by the name "forming gas".

The treatment can be carried out in a conventional vertical oven. In this case, a treatment at approximately 950°C for approximately one hour under argon or under nitrogen is then applied. This treatment can be preceded by or can comprise a phase of oxidation in order to protect the surface of the substrate 1 from the annealing environment. The oxide layer formed can then be removed on conclusion of the healing heat treatment stage by a simple chemical etching.

Particularly advantageously, the healing heat treatment is carried out in situ in the rapid heat treatment device.

By controlling the electrical energy provided to the lamps 7 of the chamber 6 of the rapid thermal annealing device on conclusion of the temperature plateau, it is possible, as is represented in Figure 5, to follow this plateau with an annealing at 950°C for a period of time of, for example, between 15 seconds and two minutes.

Alternatively, or in supplementing this annealing at 950°C, the healing heat treatment can be established by controlling the fall in temperature, on completion of the rapid heat treatment plateau, according to a lower heat gradient than 40°C per second.

This cooling, slowed down in comparison with the rapid heat treatment of the state of the art, can also be obtained simply by adjusting the electric power supplies to the lamps 7 during this cooling phase.

Whatever the embodiment of the healing heat treatment chosen, it is observed that the RF characteristic of the

substrate 1 is improved, in particular of that of second harmonic distortion, as is made apparent in the example which follows.

Two types of substrates A and B exhibiting a trapping layer 3 were prepared. The two types A and B of substrates with a diameter of 300 mm consists of a surface silicon layer 5 with a thickness of 75 nm and of a silicon oxide insulating layer 4 with a thickness of 200 nm. The trapping layer 3 consists of a layer of polycrystalline silicon with a thickness of 1.7 μm . The substrate A comprises a support 2 exhibiting a resistivity of 17 kohm.cm and the substrate B of 5 kohm.cm.

These substrates A and B are structurally designed in order to provide a second harmonic distortion value of -100 dBm for the substrate A and of -90 dBm for the substrate B. These values are obtained for similar substrates which have not received a rapid heat treatment.

The following treatments are applied to each of these two types of substrates A and B and the second harmonic distortion (HD2) is measured for each of them:

- RTA alone: rapid heat treatment, the profile of which is given in Figure 4;
- RTA + TTH: heat treatment at 950°C for one hour under argon after protective oxidation, after a rapid heat treatment identical to the preceding RTA treatment.
- RTA+: rapid heat treatment, the profile of which is given in Figure 5, comprising, subsequent to the plateau at 1200°C, a healing treatment at 950°C.

	HD2 expected	HD2 after RTA alone	HD2 after RTA+TTH	HD2 after RTA+
Substrate A	-100 dBm	-70 dBm	-101 dBm	-107 dBm

Substrate B	-90 dBm	-70 dBm	-92 dBm	-97 dBm
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It is thus apparent in the preceding table that the rapid heat treatment affects the measured performance of the substrate 1 and that this performance is at least partially recovered after the application of a healing heat treatment in accordance with the invention.

CLAIMS

1. Process for the manufacture of a semiconductor element, the process comprising a stage of rapid heat treatment of a substrate comprising a charge-trapping layer which is capable of damaging an RF characteristic of the substrate, the process being characterized in that the rapid heat treatment stage is followed by a healing heat treatment of the substrate between 700°C and 1100°C for a period of time of at least 15 seconds.
2. Manufacturing process according to the preceding claim, in which the healing heat treatment is carried out in a neutral or reducing atmosphere.
3. Manufacturing process according to either of the preceding claims, in which the healing heat treatment consists of an annealing at 950°C for one hour.
4. Manufacturing process according to one of the preceding claims, in which the rapid heat treatment stage is carried out in a rapid heat treatment device, such as a rapid annealing oven or a flash annealing device.
5. Manufacturing process according to the preceding claim, in which the healing heat treatment is carried out in situ in the rapid heat treatment device.
6. Manufacturing process according to the preceding claim, in which the healing heat treatment consists of an annealing at 950°C for a period of time of between 15 seconds and 2 minutes.
7. Manufacturing process according to Claim 5, in which the healing heat treatment is carried out by controlling the fall in temperature on completion of the rapid heat treatment at less than 40°C/s.

8. Manufacturing process according to one of the preceding claims, in which the rapid heat treatment comprises the exposure of the substrate to a treatment atmosphere for a maximum period of time of 2 minutes at a plateau temperature of between 1125°C and 1250°C.
9. Manufacturing process according to one of the preceding claims, in which the semiconductor element is an RF device.
10. Manufacturing process according to one of the preceding claims, in which the semiconductor element is a silicon on insulator wafer exhibiting a diameter of 200 or 300 mm.
11. Manufacturing process according to one of the preceding claims, in which the charge-trapping layer is a polycrystalline silicon layer.
12. Manufacturing process according to one of the preceding claims, in which the RF characteristic of the substrate is evaluated by a second harmonic distortion measurement.