

DESCRIPTION**TITLE: CARRIER COMPRISING A LAYER FOR TRAPPING ELECTRICAL
CHARGES FOR A COMPOSITE SUBSTRATE**

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FIELD OF THE INVENTION

The invention relates to a process for preparing a carrier having an electrical-charge-trapping layer, the carrier being intended
10 to receive a thin crystalline layer through a layer-transfer technique. A composite substrate formed of such a carrier is applicable in the field of integrated electronic components, in particular of radio-frequency (RF) components processing signals the frequency of which may typically be between 20 kHz and 300
15 GHz, or more. The thin layer of the composite substrate can consist of a semiconductor material such as silicon, or an insulator material, such as a material having piezoelectric and/or ferroelectric properties. In addition to the process for preparing the carrier as such, the invention also relates to the
20 process for fabricating the composite substrate comprising this carrier and to which the thin layer has been transferred.

TECHNOLOGICAL BACKGROUND OF THE INVENTION

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The prior art is full of solutions aimed at forming a carrier provided with an electrical-charge-trapping layer (more simply "trapping layer" in the remainder of this description). Such a carrier is intended to form the base substrate of a composite
30 substrate, for example of silicon-on-insulator type. The trapping layer makes it possible to limit the electromagnetic coupling that occurs between an RF component formed in or on the thin layer of the composite substrate and this carrier. The electrical traps of the trapping layer limit the mobility of the
35 charge carriers and thus the interactions with the

electromagnetic fields generated by high-frequency signals propagating into the bulk of the composite substrate. Thus the quality of the useful signals is preserved while limiting their nonlinear distortion, insertion losses and possible crosstalk between components.

Generally, it is desirable to form a trapping layer said that it has a high density of structural defects such as dislocations, grain boundaries, amorphous zones, interstices, inclusions, pores, etc. These structural defects form traps for the charges liable to flow through the material, for example at the site of incomplete or dangling chemical bonds. Conduction is thus prevented in the trapping layer, which consequently has a high resistivity.

Document US2017062284 proposes to form this trapping layer from porous silicon. However, such a layer proves to be chemically and mechanically fragile. It is liable to degrade during treatments applied to the carrier, in particular the treatments for transferring the thin monocrystalline layer during the fabrication of the composite substrate. These treatments can mechanically stress the carrier, for example during the transfer of the thin layer by splitting a donor substrate which had been previously joined thereto. They can also stress it chemically, for example during the cleaning or wet etching steps of a finishing sequence for finishing the composite substrate, applied after the transfer of the thin layer.

Document US2018047614 proposes filling the pores of the porous layer, for example using amorphous or polycrystalline silicon, by physical vapor deposition or by chemical vapor deposition of the filling material. Document US2022359272 itself proposes forming a mesoporous layer having hollow pores, the internal

walls of which are predominantly covered with oxide by annealing under an oxidizing atmosphere.

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OBJECT OF THE INVENTION

One aim of the invention is to provide an alternative way of forming an electrical-charge-trapping layer formed from a porous layer, this trapping layer being mechanically and chemically robust.

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BRIEF DESCRIPTION OF THE INVENTION

15 With a view to achieving this aim, the subject of the invention provides a process for preparing a carrier for a composite substrate, the preparation process comprising:

- 20 - a first step of porosification aimed at forming a surface porous layer on a first face (1c) of the carrier;
- a second step of providing a viscous solution comprising a solvent and a precursor of a filling material;
- 25 - a third step of dispensing the viscous solution onto the first face of the carrier so as to absorb at least part of the viscous solution in open pores of the porous surface layer;
- 30 - a fourth step of heat treatment of the carrier aimed at transforming the viscous solution present in the open pores so that they are filled with the filling material.

Due to the fact that at least some of the pores are completely filled with the filling material, the trapping layer has good mechanical strength and chemical resistance.

5 According to other advantageous and non-limiting features of the invention, taken alone or according to any technically feasible combination:

- 10 - the carrier has a resistivity of less than 10 ohm.centimeters, preferably between 1 and 2 ohm.centimeters;
- the first, porosification step is carried out by etching in an acid bath, in particular a bath comprising a mixture of
15 nitric acid and hydrofluoric acid;
- the first, porosification step is performed electrochemically or photoelectrochemically;
- 20 - the surface porous layer has a thickness of between 100 nm and 20 micrometers;
- the third, dispensing step is performed by centrifugation;
- 25 - the filling material is a dielectric;
- the filling material is silicon oxide;
- the precursor of the filling material is a hydrogenated
30 silsesquioxane resin;
- the process comprises, before the fourth, heat treatment step, a preliminary step of evaporating the solvent;

- the fourth, heat treatment step comprises exposing the carrier to a temperature between 300°C and 1100°C;
- a capping layer comprising the filling material is also formed on and in contact with the porous surface layer;
- The preparation process as claimed in the preceding claim, wherein the capping layer is removed.

10 According to another aspect, the subject of the invention provides a process for fabricating a composite substrate comprising providing a carrier prepared as presented above and transferring a thin monocrystalline layer onto the first face of the carrier.

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The thin monocrystalline layer can consist of silicon, silicon carbide or a piezoelectric material.

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BRIEF DESCRIPTION OF THE FIGURES

Other features and advantages of the invention will become apparent from the detailed description of the invention that follows, with reference to the appended figures, in which:

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[Fig. 1]

Figure 1 shows a carrier according to the invention;

[Fig. 2]

30 Figure 2 shows a composite substrate utilizing a carrier according to the invention;

[Fig. 3a]

[Fig. 3b]

[Fig. 3c]

[Fig. 3d]

Figures 3a, 3b, 3c and 3d illustrate a process for preparing a carrier in accordance with the invention.

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DETAILED DESCRIPTION OF THE INVENTION

Figure 1 shows a carrier 1 in accordance with the invention and intended to receive, through a layer-transfer technique, a thin crystalline layer in order to form a composite substrate S, shown in figure 2. Very generally, the carrier 1 comprises, on a first face 1c, a trapping layer 1a formed from a porous layer, at least some of the pores of which are completely filled with a filling material. Preferentially, a majority proportion of the pores are filled with the filling material, for example more than 50%, more than 60% or even more than 95%. This material may in particular comprise or consist of a dielectric such as a silicon oxide. Owing to its constitution, the trapping layer 1a has a high resistivity, typically greater than 10 kohm.cm over its entire thickness, and good mechanical strength and chemical resistance.

The pores can have any morphology and the porous layer, at least some of the pores of which have been filled with the filling material, can be of macroporous nature (pore diameter of greater than 50 nm), mesoporous nature (pore diameter between 2 nm and 50 nm) and/or nanoporous nature (pore diameter of less than 2 nm). Preferentially however, a material of mesoporous nature will be chosen. The porosity ratio is typically between 40% and 60%, but this does not form an essential feature of the invention.

A person skilled in the art will be able to choose, depending on the nature of the filling material, the porosity ratio and the nature of the pores which ensure a good balance between the mechanical properties and the electrical properties desired for the trapping layer 1a.

The trapping layer 1a has a thickness typically of between 100 nm and 20 micrometers, but preferably greater than 1 micrometer, or greater than 10 micrometers, a relatively thick trapping layer enabling better electromagnetic isolation of the components of the carrier. The part 1b of the carrier 1 located under the trapping layer 1a itself has a thickness of several hundred microns to ensure the mechanical strength of the assembly.

As shown as a dotted line in the illustration of figure 1, provision may be made to provide the carrier 1 with a dielectric layer 2 on and in contact with the trapping layer 1a, but this dielectric layer 2 is entirely optional. When it is present, it may consist of or comprise silicon oxide, silicon nitride and/or a silicon oxynitride.

Conventionally in the field of substrates for integrated devices, the carrier 1 may be in the form of a circular wafer, the diameter of which may be 100, 150, 200, 300 or even 450 mm.

Preferentially, the starting carrier in which the trapping layer 1a has been formed is made of monocrystalline silicon. It advantageously has a relatively low resistivity, of less than 10 ohm.cm, preferentially of the order of 1 to 2 ohm.cm, but without excluding the possibility that this substrate can have a different resistivity, as will be disclosed in the remainder of this description. It can be of p-type or of n-type.

In order to form the trapping layer 1a, and with reference to figures 3a to 3d which illustrate a process for preparing a carrier in accordance with the invention, a first step of porosification is applied to the starting carrier, aimed at forming a porous surface layer P on at least one of its faces 1c (denoted "first face" in the remainder of this description).

This step can be carried out in multiple ways. According to a first approach, the first, porosification step is carried out by etching in an acid bath, in particular a bath comprising a mixture of nitric acid and hydrofluoric acid. Reference may be made to the document by Starostina *et al.* "Porous-Silicon formation in HF-HNO₃-H₂O Etchants", *Russian Microelectronics* **31**, 88-96 (2002) for a description of the physical phenomena leading to the formation of the porous surface layer by means of such a chemical treatment.

This approach tends to form a porous surface layer P, the thickness of which is relatively thin, of the order of 1 micrometer or less. The formation of the porous layer is favored by a relatively low resistivity of the carrier 1, which may lead to selecting this carrier 1 to be of low resistivity, of the order of 10 ohm.cm or less. It is possible to envisage treating a carrier 1 so that it has, at the surface, a thickness of low resistivity, it being possible for the remainder of the carrier 1b to then have a resistivity that is more freely chosen. It may involve introducing dopants into this surface thickness or forming a doped surface layer by deposition.

According to another approach, the first, porosification step is performed electrochemically or photoelectrochemically, using a phenomenon of anodic dissolution in an acidic medium, by electrolysis. In practice, the carrier 1 is placed in an electrochemical cell, its first face 1c being exposed to an

electrolyte solution based on hydrofluoric acid (HF). This solution may have an HF concentration of greater than 30% and may comprise an additive (for example, isopropyl alcohol (IPA) or ethanol). The carrier 1 is in contact with an anode, for example in contact with the face on the opposite side from the first face 1c, a cathode being placed facing the first face 1c to allow a current to flow through the electrolyte and the carrier 1. The current density flowing in the cell (typically between 1 and 50 mA/cm²) leads to the formation of the porous surface layer on the first face 1c of the carrier 1, that is to say the face exposed to the electrolyte. This approach makes it possible to form a relatively thick porous layer P, of the order of 10 micrometers, or even 20 micrometers, by prolonging the duration of this step.

It should be noted that there are other electrochemical cell configurations that make it possible to form the porous surface layer P. In particular, "double cell" configurations are known (see, for example, document US11049724) in which the two opposite faces of the starting carrier are brought into contact either with the same electrolyte solution or with different solutions. In this case, one of the faces can be illuminated so that this face generates charge carriers during the electrochemical phase.

Irrespective of the way in which this first, porosification step has been carried out, on conclusion of this step a porous surface layer P is obtained on a first face 1c of the carrier 1. The pores constituting this porous surface layer P may, for some of them, be open and emerge (directly or indirectly) on the first face 1c of the carrier. It is possible to control the parameters of this step in order to obtain a given porosity ratio and a given nature of the pores (their mean dimensions in particular), as was mentioned in a previous passage of this description. The porosification time defines, all else being equal, the thickness

of the surface porous layer P, which is intended to form the trapping layer. Preferably, this thickness will be chosen to be between 100 nm and 20 micrometers, as has already been specified.

5 In a second step of preparing the carrier 1, a viscous solution comprising a solvent and a precursor of a filling material is prepared. This solution is intended to fill the pores of the porous layer P, it must therefore have a low viscosity to allow it to penetrate and flow into the pores of this layer P. The
10 viscosity of the solution can notably be controlled by adjusting the proportion of solvent in the solution.

In addition to the solvent, the solution comprises a precursor of the filling material. A "precursor of the filling material"
15 denotes any material which, directly or after a treatment, results in the filling material being obtained or formed, once the solvent has been removed from the viscous solution.

In a preferred embodiment, the filling material is silicon
20 dioxide and its precursor is hydrogenated silsesquioxane. Hydrogenated silsesquioxane is an inorganic compound of formula $[\text{HSiO}_{3/2}]_n$ which, after heat treatment leading to the removal of at least part of the hydrogen contained therein, forms a silicon-rich oxide SiO_2 chemically resistant to the etchant such as
25 tetramethylammonium hydroxide (TMAH or TMAOH). It can be combined with an organic solvent, for example methyl isobutyl ketone (often referred to as MIBK), to form the viscous solution.

However, the invention is in no way limited to a silicon oxide
30 filling material and to this precursor. A filling material based on silicon nitride, on silicon oxynitride or on an alloy comprising silicon and carbon can be envisaged, by using a precursor based on silicon and nitrogen, for example a chemical compound of silazane, disilazane or polysilazane type.

The use of these filling material precursor polymers is for example documented in US4312970A or US4756977A.

5 In a third step of the process for preparing the carrier substrate 1, the viscous solution is dispensed onto the first face 1c of the carrier 1 so as to absorb at least part of the viscous solution in the open pores of the porous surface layer P. This dispensing step advantageously aims to coat the first
10 face 1c of the carrier uniformly in order to make it possible to fill the open pores over the entire area of the first face 1c. This step, illustrated in figure 3b, can in particular be carried out by spin coating, by dip coating, by spray coating or by flow coating.

15 The low viscosity of the solution enables it to penetrate into the pores of the surface porous layer P in order to fill them. It will be noted that the pores of this layer which do not communicate, directly or indirectly, with the first face 1c of
20 the carrier cannot receive, by flowing, the viscous solution. However, this does not pose any obvious problem insofar as these blind pores are not the predominant pores in the surface porous layer.

25 If the viscous solution is supplied in excess, it tends to form a capping layer 4 on and in contact with the porous surface layer P. This capping layer may have a thickness of several micrometers and be very uniform, owing to the viscous nature of the solution, in particular when dispensed by centrifugation.

30 Optionally, at this stage of the process, a solvent evaporation step may be provided. This evaporation step can be obtained by simply drying the carrier or by raising its temperature in an

oven, for example to a moderate temperature of between 50°C and 300°C.

Whether or not this evaporation step has been applied, a process
5 for preparing a carrier 1 in accordance with the invention
provides, after the third step of dispensing the viscous
solution, a fourth, heat treatment step. This step, shown in
figure 3c, aims to transform the viscous solution present in the
open pores of the porous layer so that they are filled with the
10 filling material. If the preliminary solvent evaporation step
has not been applied, the solvent is removed from the solution
during this heat treatment. This also results in the removal of
the volatile species present in the precursor of the filling
material, so that, on conclusion of this heat treatment, the
15 pores are effectively filled with this material. For example,
when the precursor of the viscous solution is hydrogenated
silsesquioxane, the heat treatment results in at least part of
the hydrogen being removed from the precursor (forming in this
case the volatile species) in order to fill the pores with an
20 oxide rich in silicon and and depleted in hydrogen.

This heat treatment is of course adapted to the nature of the
viscous solution and more particularly to the nature of the
precursor present in this solution. When the latter is
25 hydrogenated silsesquioxane, the annealing may be between 300°C
and 1100°C.

When a capping layer 4 is present on the carrier, the heat
treatment step also results in the viscous material constituting
30 the capping layer being transformed. Provision may be made to
remove this layer, if it is not desirable for the use of the
carrier, for example by a polishing step. Alternatively, it can
be retained and help to form the dielectric layer 3 of the

carrier 1, if the filling material is actually dielectric in nature.

Whether or not this capping layer 4 is retained, a preparation process according to the invention may also comprise a step of forming the dielectric layer 2 on the carrier, by a conventional deposition process.

Figure 3d shows the carrier substrate 1 obtained on conclusion of this treatment (without having formed a dielectric layer 2 in the example shown). The porous surface layer P formed initially has been transformed by the trapping layer 2 formed of silicon and pores filled with a filling material.

As has already been mentioned, the carrier substrate 1 is intended to receive, by transfer, a thin layer 3 and thus form a composite substrate S, shown by way of illustration in figure 2. The thin layer 3 is generally crystalline, and advantageously monocrystalline, in nature. The carrier 1 has suitable properties (in terms of surface roughness and deformation in particular) or has been treated beforehand (for example by polishing) to receive such a thin layer 3. The composite substrate S comprises, in contact and inserted between the carrier 1 and the thin layer 3, a dielectric layer 2. This dielectric layer has a thickness chosen according to the nature of the components which will be formed in and on the thin layer 3 and therefore of the application targeted by the composite substrate S. This thickness can, for example, be between 10 nm and 10 micrometers.

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As is well known per se, the transfer of the thin layer 3 onto the carrier 1 is usually achieved by joining a free face of a donor substrate to the first face 1c of the carrier 1, preferentially by molecular adhesion. Provision is made to

provide at least one of these faces with a surface dielectric layer, these layers forming in combination the dielectric layer 2 of the composite substrate S.

5 The nature of the donor substrate is chosen according to the desired nature of the thin layer 3. It may therefore be a substrate formed of a monocrystalline semiconductor, for example silicon, or a substrate formed of a monocrystalline piezoelectric material or comprising a surface layer of such a
10 monocrystalline piezoelectric material. It may in this case be lithium tantalate or lithium niobate.

It is also possible for the donor substrate to have finished or semi-finished components, the transfer aiming to place these
15 components on the carrier 1 in order to take advantage of its radio-frequency properties.

Just like the carrier 1, the donor substrate may take the form of a circular wafer, the dimension of which may correspond to
20 that of the carrier.

After this joining step, the thickness of the donor substrate is reduced to form the thin layer 4. This reduction step can be carried out by mechanical or chemical thinning, in particular
25 when the donor substrate comprises components which it is desired to place on the carrier 1. The reduction in thickness of the donor substrate can preferentially be achieved by splitting, at a weakened plane previously introduced into the donor substrate, for example by implantation of light species such as hydrogen
30 and/or helium. This weakened plane defines, with the free surface of the donor substrate, the thin layer 3.

After this thinning, or preferentially splitting, step, steps for finishing the thin layer 3 can be applied, such as a

polishing step, a heat treatment under a reducing or inert atmosphere, a sacrificial oxidation, etc.

On conclusion of these steps, a composite substrate S formed of
5 the thin monocrystalline layer transferred onto the carrier 1 is obtained.

Needless to say, the invention is not limited to the embodiments
described, and implementation variants may be applied thereto
10 without departing from the scope of the invention as defined by the claims.

CLAIMS

1. A process for preparing a carrier (1) for a composite substrate (S), the preparation process comprising:
- 5 - a first step of porosification aimed at forming a porous surface layer (P) on a first face (1c) of the carrier (1);
 - a second step of providing a viscous solution comprising a solvent and a precursor of a filling
10 material;
 - a third step of dispensing the viscous solution onto the first face (1c) of the carrier (1) so as to absorb at least part of the viscous solution in open pores of the porous surface layer (P);
 - 15 - a fourth step of heat treatment of the carrier (1) aimed at transforming the viscous solution present in the open pores so that they are filled with the filling material.
- 20 2. The preparation process as claimed in the preceding claim, wherein the carrier (1) has a resistivity of less than 10 ohm.centimeters, preferably between 1 and 2 ohm.centimeters.
- 25 3. The preparation process as claimed in either of the preceding claims, wherein the first, porosification step is carried out by etching in an acid bath, in particular a bath comprising a mixture of nitric acid and hydrofluoric acid.
- 30 4. The preparation process as claimed in one of claims 1 to 3, wherein the first, porosification step is performed electrochemically or photoelectrochemically.

5. The preparation process as claimed in one of the preceding claims, wherein the porous surface layer (P) has a thickness of between 100 nm and 20 micrometers.
- 5 6. The preparation process as claimed in one of the preceding claims, wherein the third, dispensing step is performed by centrifugation.
7. The preparation process as claimed in one of the preceding
10 claims, wherein the filling material is a dielectric.
8. The preparation process as claimed in one of the preceding claims, wherein the filling material is silicon oxide.
- 15 9. The preparation process as claimed in one of the preceding claims, wherein the precursor of the filling material is a hydrogenated silsesquioxane resin.
10. The preparation process as claimed in one of the preceding
20 claims, wherein the process comprises, before the fourth, heat treatment step, a preliminary step of evaporating the solvent.
11. The preparation process as claimed in one of the preceding
25 claims, wherein the fourth, heat treatment step comprises exposing the carrier (1) to a temperature between 300°C and 1100°C.
12. The preparation process as claimed in one of the preceding
30 claims, wherein a capping layer (4) comprising the filling material is also formed on and in contact with the porous surface layer (P).

13. The preparation process as claimed in the preceding claim, wherein the capping layer (4) is removed.

5 14. A process for fabricating a composite substrate (S) comprising providing a carrier (1) prepared as claimed in one of the preceding claims and transferring a thin monocrystalline layer (4) onto the first face of the carrier.

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15. The fabrication process as claimed in the preceding claim, wherein the thin monocrystalline layer (4) consists of silicon, silicon carbide or a piezoelectric material.