TRANSFER METHOD OF A THIN LAYER INCLUDING AN OVEREMBRITTLEMENT STEP

Technical field

The present invention concerns transfer method of a thin layer of a substrate, called source substrate, on a support called target substrate.

The invention finds applications in particular in the fields of microelectronics, micromechanics, integrated optics and integrated electronics.

For example, it enables the production of structures in which the thin layer, which is made from material selected for its physical properties, is transferred on a support in order to form a stack with several layers. Thus, the advantages of materials of the thin layer and the support may be combined. The transfer of a layer especially enables parts to be combined in the same structure that a priori present incompatibilities such as a significant difference in the thermal expansion coefficients.

State of the prior art

The text that follows refers to a certain number of documents for which the complete references are specified at the end of the description.

Among the methods generally used for the formation of thin layers, in particular a splitting method may be mentioned, well known under the name "Smart-cut" and illustrated by document (1).

The "Smart-cut" method is essentially based on the implantation of hydrogen or another gas in neutral or ionic form in a substrate in order to form there an embrittled splitting zone.

In the case of a flat substrate, the splitting zone extends, approximately parallel to its surface and is located in the substrate at a depth set by the implantation energy. The splitting zone thus delimits a thin superficial layer in the substrate that extends in thickness from the splitting zone to the surface of the substrate.

A second step comprises the adhesion of the source substrate to the target support so that the thin layer is integral with the target support. The attachment of the thin layer to the target support may take place by means of glue and/or through a bonding layer. It may also take place by direct molecular adhesion between the substrate surface and the surface of the target support.

In this latter case, however, it is necessary for the surfaces that one desires to adhere have certain properties such as good flatness and low surface roughness.

A last step in the method consists of fracturing the substrate along the splitting zone to separate the thin layer from it. The latter then remains integral with the target support.

In the case of the method described by document (1), the fracture (or splitting) of the substrate is caused by energy supply in the form of a heat treatment.

The implantation conditions define the splitting zone and govern the separation of the thin layer from the substrate.

Now, it has been observed that too great an embrittlement of the splitting zone after implantation, although favourable for separation, causes deformations in the surface of the thin layer. The deformations are presented in the form of blisters and form an obstacle for attachment of the thin layer to the target support.

This embrittlement that is too great may be linked to high-dose ionic implantation or to lower-dose ionic implantation combined with annealing. Too great an embrittlement may therefore induce the appearance of blisters on the surface all the more easily since the embrittled zone is near the surface.

In certain applications it is desired to obtain self-supported thin films, that is, that may be separated from the source substrate without being previously attached to a support.

These thin films may then be transferred later to different target supports and, in particular, to supports with which the source substrate may not be adhered before separation of the thin layer, for example, for reasons of compatibility of thermal expansion coefficients.

On this subject reference may be made to document (2) which proposes a method derived from that of document (1).

Document (2) proposes a method enabling the separation of its original substrate from a thin film

which is self-supported. For that, it is necessary for the implanted gas species to be found at sufficient depth and/or that, after the implantation step, a layer of material is deposited that enables the structure to be made rigid to obtain separation at the level of the implanted zone without having blisters.

The illustration of the technique for formation of thin layer by splitting of a substrate may be completed by document (3) which suggests completing the fracture (splitting) heat treatment of the substrate by exerting mechanical bending, tensile or shear forces.

Document (4) which also describes a method based on the principle established by document (1) shows that the thermal budget used to cause the fracture of the source substrate depends on thermal budgets of all the heat treatments imposed on the source substrate since implantation up to fracture.

Thermal budget is understood to be the duration of heat treatment/temperature of heat treatment pair.

In a certain number of applications, it is necessary to assemble a thin layer of a source substrate with a target support that presents a thermal expansion coefficient different from that of the source substrate.

In these applications, it generally tricky to subject the structure obtained after assembling the source substrate and the target support, with a heat treatment with a thermal budget sufficient to guarantee the separation of the thin layer from the source substrate.

One solution to this problem then consists of modifying the implantation conditions by carrying out overdosage of implanted species. Such an overdosage in fact, enables the thermal budget of the separation fracture (splitting) to be reduced.

By way of example, when the source substrate is a silicon wafer a dose of implanted hydrogen ions of $1 \times 10^{17}/cm^2$ instead of $6 \times 10^{16}/cm^2$ for a heat treatment duration of several hours enables its temperature to be lowered to 280°C from 400°C.

The solution consisting of overdosing the implantation however is not always satisfactory because of the difference of the thermal expansion coefficient that may exist between the substrate and the support. In fact, the thermal budget necessary for the separation may be such that it causes the separation of the substrate and the support and/or the break of the substrate and/or the support in their bulk.

An alternative solution to avoid a separation between the thin layer and the target support under the effect of differential expansion consists of thinning down the source substrate before the fracture (splitting) step.

This solution, suggested by document (5) however, presents the drawback of an additional thinning operation and that of consumption of significant material.

The use of mechanical forces for separating the source substrate from the thin layer, such as mentioned above with reference to document (3), also enables

reduction of the fracture thermal budget, especially in the case where the materials in contact present different thermal expansion coefficients. The exerting of mechanical forces on the source substrate and/or the target support is not always possible however, especially when the materials used are fragile or when the splitting zone is not embrittled enough by ionic implantation.

Finally, the techniques of thin layer separation and transfer, described above, involve a certain number of constraints and compromises. These constraints are imposed in particular by the type of materials used to form the source substrate, the thin layer and the target support.

Statement of the invention

The present invention has the goal of proposing a transfer method of a thin layer, not presenting any difficulties and limitations of the procedures given above.

One goal is in particular to propose such a procedure which uses a reduced, even zero, thermal budget to obtain a separation fracture of the thin layer.

Another goal is to propose an adapted transfer method of thin layer on a target support, in which the materials of the thin layer and the target support present different thermal expansion coefficients.

Still another goal is to propose a transfer method in which excellent surface state of the source substrate (without blisters) may be preserved so as to allow good

adhesion with the target support, with or without binding support (glue), and by enabling a very embrittled splitting zone to be obtained.

Lastly, a goal of the invention is to propose a transfer method enabling a thin layer to be obtained on the target support after transfer, which presents a free surface with low surface roughness.

To reach these goals, the invention more precisely has as a goal a transfer method of a thin layer of a source substrate on a target substrate including the following steps in order:

a) implantation of ions or gas species in the source substrate so as to form there a zone, called splitting, which delimits said thin layer in the substrate source,

b) transfer of the source substrate on the target support and the interlocking of the thin layer with the target support,

c) separation of the thin layer from the source substrate along the splitting zone,

In conformance with the invention, prior to step b) the method includes:

- formation of a film thickness with material between the splitting zone and the surface of the substrate such that this thickness is greater than, equal to or near a limit thickness in order for the film to be self-supported, and

- overembrittlement of the splitting zone (16) caused by heat treatment and/or exerting mechanical forces on the source substrate.

According to a first production method of the invention, the step for formation of a film thickness consists of carrying out implantation step a) so as to obtain the splitting zone at said thickness, the film then being formed by the thin layer.

According to a second production method of the invention, the step for formation of a film thickness consists of carrying out a step for formation of a layer called thickener on the thin layer, the thin layer and the thickness layer then forming the film.

The limit thickness of the film is the thickness enabling the structure to be made rigid to obtain separation of the film at the splitting zone without appearance of surface blisters. It is this limit thickness that enables self-supported films to be obtained. This thickness depends in particular on mechanical properties of the materials, but also on separation conditions of step c) for example, such as the increase in temperature of the heat treatment.

According to an advantageous method, the invention also includes the production, before step b), of all or part of microelectric and/or micromechanical and/or optoelectronic components.

The separation of the thin layer from the source substrate performed in step c), may take place under heat treatment, mechanical forces or these actions combined.

Now, as a result of the overembrittlement step, the thermal budget and/or the mechanical forces used during step c) for the separation fracture may be specifically

reduced. This has the goal of not causing the adhesion between the thin film and the target support to break, even in the case of a difference in thermal expansion coefficients of materials placed in contact.

Another advantage of the invention is to suppress or reduce the mechanical forces exerted on the parts in contact and thus to avoid their deterioration. The separation is thus made easier.

It is advisable to note that the overembrittlement step is not limited by the effects of constraints of differential expansion insofar as this step is carried out before the transfer of the source substrate on the target support (step b).

According to an advantageous aspect, the overembrittlement step includes heat treatment used with a thermal budget greater than or equal to 50%, and preferably greater than 60%, of the overall thermal budget enabling the separation.

The overall thermal budget considered here takes into account not only the heat treatments performed within the strict framework of the method of the invention, but also comprises possible heat treatments used, for example, for the production of components of for depositing materials on the thin layer between steps a) and b).

As mentioned previously, steps c) and the overembrittlement step may include exerting mechanical forces.

These mechanical forces comprise, for example, the application of forces in the form of mechanical pressure and/or mechanical stress and/or forces in the form of gas pressure.

The separation heat treatment may also be chosen sufficient to cause separation of the thin layer during step c) by simple distance between the source substrate and the target support or a total separation only by this heat treatment.

The implantation step a) enables the formation of cavities in the source substrate located within the splitting zone.

The cavities (or microcavities or platelets or microbubbles) may be presented in different forms. They may be spherical and/or flattened with at thickness of only several interatomic spacings. Moreover, the cavities may contain a free gas phase and/or atoms of gas derived from implanted ions, attached to the atoms of material forming the walls of the cavities, or containing very little gas or even no gas.

The heat treatments undergone by the source support, and in particular an overembrittlement heat treatment of the method, lead to the coalescence of all or part of the cavities. The coalescence thus causes the overembrittlement of the substrate in the splitting zone.

In addition, this phenomenon enables a free surface of the thin layer with low surface roughness to be obtained after the transfer and the separation fracture.

The layer of thickener, for example from Si, SiO_2, Si_3N_4 or even SiC, covers all or part of the thin layer. The thickness of the thickener layer to obtain a film thickness is chosen for example in a range from 3 to 10 µm for a SiO_2 thickener.

It is advisable to point out that a layer used as thickener layer may be a layer that is also used in all or in part for the production of electronic, optoelectronic or mechanical components on the surface of the thin layer.

The invention also concerns a transfer method of a thin layer of source substrate including the following steps:

a) implantation of ions or gas species in the source substrate so as to form there a zone, called splitting, which delimits said thin layer in the substrate source,

b) the separation of the thin layer from the source substrate along the splitting zone,

in conformance with the invention, the method includes prior to step b):

- formation of a film thickness with material between the splitting zone and the surface of the substrate such that this thickness is greater than, equal to or near a limit thickness in order for the film to be self-supported, or

- overembrittlement of the splitting zone caused by heat treatment and/or exerting mechanical forces on the source substrate.

The invention enables very significant overembrittlement to be obtained that may go up to 80 to 90% of the completer separation as a result of the presence of a thickener. This thickener is deposited on the surface with the goal of increasing the overembrittlement.

Other characteristics and advantages of the invention will appear better with the description which will follow, in reference to the figures of the enclosed drawings. This description is given purely by way of illustration and is not limiting.

Brief description of the figures

- Figure 1 is a diagrammatic section of a source substrate and illustrates an operation for implantation of ions.

- Figure 2 is a diagrammatic section of a source substrate of Figure 1 and illustrates the formation of a thickness layer.

- Figure 3 is a diagrammatic section of a source substrate of Figure 2 and illustrates an overembrittlement step.

- Figure 4 is a diagrammatic section of a structure formed of the source substrate of Figure 3, transferred on a target support.

- Figure 5 is a diagrammatic section of the structure of Figure 4 after separation fracture of the source substrate.

Detailed description of a method for use of the invention

The description that follows is related to transfer of a thin layer of silicon on a target support of fused silica (improperly called quartz).

However, the invention may be used for other solid materials, whether or not they are crystalline. These materials may be dielectric, conductor, semi-insulating or semiconductor.

Likewise, the target support may be a final or an intermediate support, such as a handle, massive substrate or multilayer substrate.

In particular, the method may be taken advantage of for the transfer of layers of non-semiconductor, ferroelectric, piezoelectric materials such as for example, LiNbO3, or III-V semiconductors such as AsGa, InP on silicon or SiC.

Figure 1 shows an initial silicon substrate 10. The latter undergoes implantation of hydrogen ions indicated with arrows 12. This implantation corresponds to step a1) of the method.

The implantation, carried out for example with a dose of 6 x $10^{16}/cm^2$ and an energy of 70 kev, enables formation of microcavities 14 in substrate 10 at a depth on the order of 7000 Å.

This depth also corresponds to the thickness of the thin layer 18. The latter is delimited at the surface of the substrate by a zone 16, called splitting, comprising microcavities 14.

Prior to, or preferably after, this implantation the superficial thin layer 18 may be subjected to other treatments, known in themselves, for the formation of electronic, optical or mechanical components in this layer. These components are not represented in the figure for reasons of clarity. In this case, these steps are taken into account for overembrittlement.

Likewise, for better readability of the figures, the different layers or characteristics represented are not represented according to a uniform scale. In particular, the very thin layers are represented with an exaggerated thickness.

Figure 2, which corresponds to the step for use of a thickness of the procedure, shows the depositing of a layer of silicon oxide 20 with a thickness on the order of, or greater than 5 μm, on the thin layer 18. The layer of silicon oxide is for example deposited by a plasma-assisted chemical gas-phase deposition at a temperature of 300°C. The thermal budgets are chosen so that they avoid the appearance of blisters during the step for production of the thickness.

The layer of silicon oxide 20 acts as thickener of the thin layer 18. In other words, it has the goal of preventing deformation of the thin layer under the effect of later heat treatments.

Figure 3 corresponds to the overembrittlement step of the method. During this step, the substrate undergoes treatments aiming to embrittle the splitting zone 16 even more.

In the example illustrated, one proceeds with a heat treatment that is carried out at a temperature on the order of 450°C for a period on the order of 12 min.

This thermal budget is preferably higher than 60% of the thermal budget necessary to obtain separation only by annealing. Such overembrittlement is possible with sufficient thickness of the film.

It is observed that the heat treatment causes partial coalescence of the microcavities 14 and the splitting zone 16.

During this operation, the thickness layer 20 which covers the thin layer 18, prevents its deformation and in particular, prevents the formation of blisters.

In the absence of this layer, blisters would be likely to appear with a heat treatment at 450°C after a period on the order of 2 min, which corresponds only to a heat treatment 10% of that of the heat treatment necessary for the separation.

The heat treatment may be followed by a polishing step of the free surface of the thickener layer 20 just to improve the roughness of the surface so as to prepare for molecular gluing.

Figure 4 shows the transfer of the source substrate 10 on a target support 30 which, as it happens, is a quartz wafer.

The transport is carried out so as to place a flat surface of the target support in contact with the free flat surface of the thickener layer 20.

Molecular adhesion forces exerting at the level of the surfaces placed in contact ensure the interlocking (attachment) between the source substrate and the target support.

When such a molecular adhesion is not possible because of the nature of materials or the quality of the surface, the transfer may take place through a binder or glue.

The molecular adhesion forces may be reinforced for example by heat treatment and/or surface preparations. In the example illustrated, and because of great differences in thermal expansion coefficients between the silicon and the quartz, the heat treatment is carried out at a relatively low temperature, on the order of 200°C, for a period of 20 h.

This heat treatment may contribute to inducing constraints such as; the fracture of the substrate may be obtained along this zone.

Figure 5 illustrates step c) of the method which corresponds to a fracture of the source substrate. The fracture takes place along the splitting zone and separates the thin layer 18 from the remaining part of the substrate 10. This latter part then may be reused for example for a new thin layer transfer.

The thin layer 18 remains integral with the support 30 through the thickener layer 20.

In another example, not represented, where the thickness of the thin layer is extensive enough to avoid deformations, the thickener layer may be omitted. The

thin layer is then directly in contact with the target support.

By way of example, the use of a substrate of SiC may be mentioned, that is implanted with approximately 200 KeV so as to obtain a film of approximately 1.5 µm without thickener. In this example, the overembrittlement may be obtained without thickener.

The fracture of the source substrate may be caused by exerting a mechanical force and/or by a heat treatment.

In the example illustrated, a razor blade (not represented) may be inserted by hand at the level of the embrittled zone.

The invention applies particularly well to the production of a thin layer of silicon on the fused silica in which the principal concern is to have a transparent support with a semiconductor layer that may include components.

DOCUMENTS CITED

(1) FR-A-2 681 472 (US-A-5 374 564)

(2) FR-A2 738 671 (US-A-5 714 395)

(3) FR-A-2 748 851

(4) FR-A-2 767 416

(5) FR-A-2 755 537



CLAIMS

1. Transfer method of a thin layer (18) of source substrate (10) on a support target (30) including the following steps:

a) implantation of ions or gas species in the source substrate so as to form there a zone (16), called splitting, which delimits said thin layer (16) in the substrate source,

b) transfer of the source substrate on the target support and the interlocking of the thin layer with the target support,

c) separation of the thin layer (18) from the source substrate (10) along the splitting zone,

characterized in that it includes prior to step b):

- formation of a film thickness with material between the splitting zone and the surface of the substrate such that this thickness is greater than, equal to or near a limit thickness in order for the film to be self-supported, and

- overembrittlement of the splitting zone (16) caused by heat treatment and/or exerting mechanical forces on the source substrate.

2. Method according to Claim 1 in which the separation of the thin layer (18) from the source substrate (10) is caused by a heat treatment and/or by exerting mechanical forces.

3. Method according to Claim 1 or 2 in which the overembrittlement includes a heat treatment used with a thermal budget enabling the separation.

4. Method according to Claim 2 in which the heat treatment for separation is chosen to be sufficient for causing, during step c), separation of the thin layer (18) by simple distance between the source substrate and the target support or a total separation only by this heat treatment.

5. Method according to Claim 1 in which step c) and the overembrittlement step include exerting forces in the form of a mechanical pressure and/or mechanical stress and/or forces in the form of gas pressure.

6. Transfer method of a thin layer (18) of source substrate (10) including the following steps:

a) implantation of ions or gas species in the source substrate so as to form there a zone (16), called splitting, which delimits said thin layer (18) in the substrate source,

b) separation of the thin layer (18) from the source substrate (10) along the splitting zone,

in conformance with the invention, the method includes prior to step b):

- formation of a film thickness with material between the splitting zone and the surface of the substrate such that this thickness is greater than, equal

to or near a limit thickness in order for the film to be self-supported, and

- overembrittlement of the splitting zone (16) caused by heat treatment and/or exerting mechanical forces on the source substrate.

7. Method according to Claim 1 characterized in that the step for formation of film thickness consists of producing step a) of implantation so as to obtain a splitting zone at said thickness, the film then being formed by the thin layer.

8. Method according to Claim 1 in which the step for formation of a film thickness comprises the production of a layer called thickener (20) on the thin layer, the thin layer and the thickener then forming the film.

9. Method according to Claim 1 comprising in addition, the production before step b) of all or part of microelectronic and/or micromechanical and/or optoelectronic components.