A METHOD OF FABRICATING A SUBSTRATE, IN PARTICULAR FOR OPTICS, ELECTRONICS, OR OPTOELECTRONICS, AND A SUBSTRATE OBTAINED BY THE METHOD

The invention relates to the field of methods of fabricating substrates, in particular for optics, electronics, or optoelectronics, and also to substrates obtained by such methods. More particularly, the substrates can be intended for making microsystems, sensors, light-emitting or laser diodes, etc.

Document FR 2 681 472 discloses a method of fabricating substrates in which a thin layer of a material is transferred from a source substrate onto a support. Under such circumstances, the operation of bonding the thin layer to the support is often achieved by molecular adhesion, and in order to obtain a good adhesive interface it requires the surfaces that are to be stuck together to be prepared specially prior to being brought into contact. Such preparation generally comprises operations of polishing, planarizing, physico-chemical treatment, making intermediate layers, etc. and can be relatively lengthy and complex. This applies in particular when the supporting substrate is polycrystalline.

An object of the invention is to provide a method of fabricating a substrate comprising a thin layer on a support, which method is significantly simplified compared with prior art methods and can be much less expensive.

According to the invention, this object is achieved by a method of fabricating a substrate comprising a thin layer carried by a layer constituting a mechanical support, in particular for optics, electronics, or optoelectronics, the method comprising the following steps:

· detaching a layer of material for forming the thin layer from a source substrate; and then

· making a thick layer on the thin layer by depositing material to form the layer which constitutes the mechanical support.

The method of the invention is simple to implement and it enables lengthy and expensive preparation of the surfaces that are to be brought into contact, such as polishing, planarizing, making intermediate layers, etc. to be omitted, all of which steps can optionally be replaced merely by etching prior

to forming the thick layer, which formation can advantageously be accompanied by high temperature treatment.

In particular, in existing techniques of transferring a thin layer onto a thick support (and regardless of whether the thin layer is monocrystalline, polycrystalline, amorphous, etc.), a thin layer is transferred as a single piece onto a previously-prepared thick support, likewise constituted by a single piece, whereas in the present invention the thick support is formed directly on the thin layer. Thus, implementing the method of the invention gives rise to substantial savings because it makes it possible to omit the lengthy and expensive steps of preparing surfaces.

Advantageously, in the invention, the material constituting the support is deposited directly on the thin layer, e.g. by chemical vapor deposition (CVD). Under such circumstances, the interface that is obtained between the thin layer and the support is of excellent quality, particularly in terms of electrical and/or thermal conductivity, which is not generally the case with prior art methods.

The thick layer can also correspond to depositing metal, e.g. an electrolytic deposit of copper.

However the thick layer can equally well be formed from a material that is molten and/or viscous or sintered.

The method of the invention is advantageously implemented for making substrates in which the thin layer and the thick layer are constituted by materials possessing respective coefficients of thermal expansion and/or crystal lattice parameters that are close or identical.

The method of the invention is also particularly advantageous in the context of making composite substrates comprising a monocrystalline thin layer, e.g. of a semiconductive material, on a support substrate that is polycrystalline, amorphous, ceramic, multiphase, etc. Certain techniques, in particular certain deposition and/or growth techniques, enable thick layers to be formed at low cost. Thus, forming a thick layer of amorphous or polycrystalline silicon carbide, for example, on a thin layer of monocrystalline silicon carbide, using the method of the invention makes it possible to form

silicon carbide substrates at a cost that is lower than it would be if the substrate were to be made completely out of high quality monocrystalline silicon carbide.

Furthermore, the method of the invention has the advantage of encouraging good quality growth of the material constituting the support. Thus, when it is desired to make substrates at lower cost, it is possible in prior art methods to transfer a thin monocrystalline layer onto an inexpensive support such as a support made of polycrystalline or amorphous material. When the same idea is transposed to the method of the invention, a thick layer of inexpensive material is made on the thin layer of a material having high added value, however if the thin layer is itself monocrystalline, then the thick layer will be of better quality than it would have been if a one-piece layer of the same material as said thick layer had been transferred directly onto the thin layer. If the support, i.e. the thick layer that is formed by the method of the invention, is a polycrystal, then better cohesion and better orientation of the various grains are obtained within that material, as is growth of privileged phases. However this advantage can be diminished if the method of the invention includes an operation of forming an intermediate layer, e.g. an amorphous insulator, between the thin layer and the support.

Under certain conditions, when the thick layer is grown on the thin layer by using the method of the invention, the thin layer serves as a seed for seeding monocrystalline or quasi-monocrystalline growth in the thick layer. These conditions correspond to the thick layer being grown epitaxially or quasi-epitaxially on the thin layer.

The method of the invention includes advantageously, but optionally, the following characteristics taken separately or in combination:

· it comprises an operation consisting in depositing a useful layer on one and/or the other of the faces of the thin layer; by way of example, this useful layer can be a material having a large band gap, such as gallium nitride, aluminum nitride, or another such material, e.g. a compound of at least two elements taken from the list comprising aluminum, indium, and gallium;

· at least one useful layer is deposited before the thick layer is formed;

· at least one useful layer is deposited after the thick layer is formed;

· the useful layer and the thick layer are each deposited on a different face of the thin layer;

· the thin layer is constituted by a monocrystalline material;

· the thick layer is formed by depositing a material taken from the list comprising: monocrystalline materials, polycrystalline materials, amorphous materials, materials comprising a plurality of phases, and materials that are less expensive than the material constituting the thin layer;

· it includes an operation of forming a bonding layer on the thin layer, said bonding layer being constituted by a material taken from the list comprising: amorphous materials and polycrystalline materials and metallic materials such as tungsten or tungsten silicide; it being understood that these properties can be combined (e.g. polycrystalline and metallic); the bonding layer can be formed before the thin layer is detached from the source substrate, for example;

· it includes a step of transferring the thin layer onto an intermediate support prior to forming the thick layer on the thin layer;

· it includes an operation consisting in eliminating the intermediate support;

· the intermediate support is eliminated by separating the thin layer from the intermediate layer, in particular in order to be able to recycle the intermediate layer;

· it includes an operation of forming a bonding layer on the intermediate support before transferring the thin layer thereon, said bonding layer being constituted of a material taken from the list comprising: amorphous materials, polycrystalline materials, and metallic materials such as tungsten or tungsten silicide; it being understood that these properties can be combined (e.g. polycrystalline and metallic);

· the thin layer is constituted by a material taken from the list comprising: silicon, silicon carbide, sapphire, diamond, gallium nitride,

aluminum nitride, and a combination or a superposition of at least two of these materials;

· the thick layer is formed of a material taken from the list comprising: silicon, silicon carbide, diamond, sapphire, graphite, gallium nitride, aluminum nitride, boron nitride, and a combination or a superposition of at least two of these materials;

· the thin layer is detached from the source substrate via a zone of weakness;

· the zone of weakness is made by implanting atomic species in the source substrate in the vicinity of a determined depth;

· the thin layer is detached from the source substrate by eliminating, e.g. by chemical etching, a zone that is interposed between the thin layer and the remainder of the source substrate; and

· the conditions under which the thick layer is deposited are optimized so that the thick layer has a particular quality taken from the list of qualities comprising: monocrystalline, polycrystalline, insulating, and conductive; it being understood that two of these qualities can optionally be associated, such as the monocrystalline and conductive qualities.

Above, and below in this document, the term "atomic implantation" covers all kinds of bombardment with atomic or ionic species suitable for causing said species to be introduced into a material so as to obtain a concentration maximum of said species in the material, the maximum being situated at a determined depth relative to the bombarded surface. The atomic or ionic species are introduced into the material with energy distributed around a maximum. Atomic species can be implanted into the material by using an ion beam implanter, an implanter that operates by immersion in a plasma, etc. The term "atomic or ionic species" is used to cover an atom in ionized, neutral, or molecular form, or any molecule in ionic or neutral form, or indeed a combination of different atoms or molecules in ionic or neutral form.

Other aspects, objects, and advantages of the invention will appear on reading the following detailed description, and the invention will also be better understood with the help of the accompanying drawings, in which:

· Figure 1 is a diagram showing the steps in an implementation of the method in accordance with the invention;

· Figure 2 is a diagram of the steps in another implementation of the method in accordance with the invention;

· Figure 3 is a diagram of the steps in yet another implementation of the method in accordance with the invention;

· Figure 4 is a diagram of the steps in yet another implementation of the method in accordance with the invention;

· Figure 5 is a diagram of the steps in yet another implementation of the method in accordance with the invention;

· Figure 6 is a diagram of the steps in yet another implementation of the method in accordance with the invention;

· Figure 7 is a diagrammatic perspective view of an intermediate support with four thin layers, as can be used in a variant of the method of the invention; and

· Figures 8a and 8b are diagrammatic section views showing examples of substrates obtained in a variant of the method of the invention.

The method of the invention is described below in detailed manner with reference to five particular but non-limiting implementations thereof.

In a first implementation, as shown in Figure 1, a final substrate 14 is made comprising a thin layer 2 on a thick layer 4 forming a mechanical support for the thin layer, by performing the following steps:

· forming a layer of amorphous material to make a bonding layer 10 on a surface of a source substrate 6 that is to be subjected to the implantation of atomic species, forming a layer of amorphous material on a surface of an intermediate support 12 to make another bonding layer 11;

· implanting atomic species at a determined depth in the source substrate 6 to form a zone of weakness 8;

· 100, putting the bonding layers 10 and 11 into contact;

· 200, detaching the thin layer 2 from the source substrate 6 via the zone of weakness 8;

· 300, depositing the thick layer 4 on the surface of the thin layer 2 that corresponds to the zone of weakness 8; and

· 400, eliminating the bonding layers 10 and 11 to separate the thin layer 2 from the intermediate layer 12.

The steps of forming the bonding layer 10 and of implanting atomic species can be performed in the order specified above, or in another order.

The step of implanting atomic species and the step 200 of detaching the thin layer 2 are described in French patent FR 2 681 472, for example.

The steps of forming the bonding layers 10 and 11 correspond to forming a layer of amorphous material using one of the methods known to the person skilled in the art.

It should be observed that the thin layer 2 can be subjected to additional technological steps, prior to being subjected to the step 300 of depositing the thick layer 4, in order to form all or some electronic components, or it can have additional films deposited uniformly thereon, epitaxially, or otherwise.

The following table summarizes examples of materials that can be used for implementing the first implementation described above.

Table 1

Thin layer 2	Intermediate support 12	Supporting thick layer 4	Bonding layers 10, 11
Mono SiC	Poly SiC or mono SiC	Poly SiC or poly AlN or diamond or mono SiC of quality inferior to that of the thin layer	SiO_2 or Si_3N_4
Mono GaN	Poly SiC or mono SiC or sapphire	Poly SiC or poly AlN or poly GaN or diamond or mono SiC of quality inferior to that of the thin layer	SiO_2 or Si_3N_4
{111}, {100} etc. mono Si	Poly Si or mono Si or poly SiC or mono SiC	Poly Si or mono Si of quality inferior to that of the thin layer	SiO_2 or Si_3N_4

In the above table, as in the following tables, the term "mono" is used to mean "monocrystalline" and the term "poly" is used to mean "polycrystalline".

EXAMPLE 1

The first example corresponds to the first row of Table 1.

The first implementation is particularly advantageous for forming a substrate comprising a thin layer 2 of monocrystalline silicon carbide on a thick layer 4 of polycrystalline silicon carbide.

Silicon carbide is difficult to obtain in single crystal form, even with diameters that are much smaller than those which are commonly obtained for

silicon single crystals. This is due in particular to the crystal-drawing techniques which are more complex and expensive for monocrystalline silicon carbide than for monocrystalline silicon, and is also due to the substrate forming steps being more difficult, more time consuming, and more expensive, given the unfavorable ratio between the hardness and the brittleness of silicon carbide.

The method of the invention is thus particularly advantageous for making substrates with thin layers 2 of silicon carbide since it enables multiple thin layers 2 to be taken from a source substrate 6 and each of those thin layers 2 to be transferred to a thick layer 4 of low cost.

Furthermore, the applications of silicon carbide lie mainly in high power semiconductor devices. Unfortunately, in such applications, certain very restrictive specifications limit the support substrates that are suitable to be selected for receiving the thin layer 2 of silicon carbide. In some circumstances, such applications require the support to have good electrical and thermal conductivity. Polycrystalline silicon carbide satisfies these requirements. In some of its properties, it is very close to monocrystalline silicon carbide: it provides a good match in terms of thermal expansion coefficient and it is compatible with treatment at temperatures that can be as high as 1600°C or 1700°C (temperatures that are required for restarting silicon carbide epitaxy and for annealing after atomic species have been implanted).

Furthermore, the use of polycrystalline silicon carbide requires little modification to the technologies of those who commonly use monocrystalline silicon carbide.

Finally, polycrystalline silicon carbide presents good properties of withstanding chemical attack.

When making a thin layer 2 of monocrystalline silicon carbide on a thick layer 4 of polycrystalline silicon carbide, the bonding layers 10 and 11 are advantageously made of silicon oxide.

The thick layer 4 can be made by chemical vapor deposition (which has the major advantage of being capable of being performed at relatively low

deposition temperatures, i.e. at about 1350°C for silicon carbide), by vapor phase epitaxy (VPE) or hydride vapor phase epitaxy (HVPE), by high temperature chemical vapor deposition (HTCVD), or by other equivalent techniques. The thick layer 4 can also be made using techniques derived from those generally implemented for making single crystals, such as subliming techniques or other techniques generally used in methods for drawing balls. The use of such techniques is not always good from the point of view of deposition quality (low temperatures, non-uniform conditions, high rates of growth, etc.), but it can be advantageous from the point of view of cost.

For silicon carbide substrates having a diameter of 50 millimeters (mm), the thick layer 4 is advantageously 300 microns (µm) thick. The thick layer 4 of silicon carbide is advantageously made by chemical vapor deposition with growth taking place at a rate of about 100 µm per hour.

Furthermore, using a surface corresponding to the monocrystalline material of the thin layer 2 for depositing 300 the thick layer 4, deposition parameters can be optimized so as to produce a monocrystalline support substrate. Thus, under these circumstances, the thin layer 2 serves as a seed for growing a monocrystalline thick layer 4. Depending on the degree of optimization of the deposition parameters and depending on the intended application, this monocrystalline thick layer 4 can be of poor or of medium quality, but the resulting substrate will nevertheless present the advantage of being of relatively low cost. However, it is also possible for the monocrystalline thick layer 4 to be of good or of very good quality if the application intended for the substrate requires that. The thick layer 4 can be grown in such a manner as to form a substrate with a layer 4 that is very thick, i.e. that is a great deal thicker than a few hundreds of micrometers, depending on the application. In variants of the implementation described above, the thick layer 4 can be made not only of silicon carbide, but of polycrystalline aluminum nitride, of diamond, or of other materials.

The intermediate support 12 must be capable of withstanding the conditions in which the thick layer 4 of silicon carbide is grown, and must also

be capable of being eliminated. The technique selected for removing the intermediate support 12 can determine the material selected for making it. If it is desired to sacrifice it by etching or by mechanical or chemical removal, then the steps of etching and removal, and also the intermediate support 12 itself must be of low cost. Under such circumstances, it is advantageous to use aluminum nitride. Low cost silicon can also be used, but it is more difficult to make compatible with depositing the silicon carbide of the thick layer 4. In contrast, if the intermediate support 12 is removed and recovered, then it is possible to use materials that are more expensive. Under such circumstances, it is possible to select polycrystalline silicon carbide or even, possibly, monocrystalline silicon carbide since it is not consumed and can be reused.

Advantageously, an intermediate support 12 is used made of polycrystalline silicon carbide covered in a bonding layer 11 of silicon oxide.

The use of silicon oxide makes it easier to take the thin layer 2 from the source substrate 6. Planarized deposition of silicon oxide makes it possible to eliminate surface irregularities and to perform steps of polishing, planarizing, cleaning, chemical preparation, and bonding silicon oxide on silicon oxide by techniques that are known and easy to implement.

The silicon oxide of the bonding layers 10 and 11 can also be replaced by some other material, for example silicon nitride (Si_3N_4). This material can withstand higher temperatures than silicon oxide. This advantage is particularly suitable for optimizing deposition of a thick layer 4 for the purpose of forming a high quality monocrystalline or polycrystalline layer, or indeed when it is desired to increase the rate of deposition.

This first example of an implementation of the method of the invention then comprises the following steps:

· making a structure constituted by a stack comprising a thin layer 2 of monocrystalline silicon carbide, two bonding layers 10 and 11 of silicon oxide, and an intermediate support 12 of polycrystalline or monocrystalline silicon carbide; this structure is made by a layer transfer method known to the

person skilled in the art (e.g. an application of a Smart-Cut® method of the kind described in French patent No. FR 2 681 472);

· 300, depositing a supporting thick layer 4 of silicon carbide, e.g. by CVD at 1350°C onto the free surface of the thin layer 2;

· 400, eliminating the bonding layers 10 and 11 by chemical etching in a bath of hydrofluoric acid and recovering the intermediate support 12; the silicon carbide which can be in polycrystalline or monocrystalline form is inert in hydrofluoric acid, whereas silicon oxide etches very easily in this substance; and

· final rough polishing of the surface of the thick layer 4 of polycrystalline silicon carbide; rough polishing being sufficient since it constitutes the rear support face of the final substrate 14; when the thick layer 4 is deposited under good control, it is even possible to omit this polishing step.

If necessary, the geometrical shape of the final substrate 14 is retouched, e.g. to ensure that the final substrate 14 has the desired diameter, to shape the way its sides drop, to eliminate nodules from the edge of the substrate, etc.

Also advantageously, the front face of the silicon carbide single crystal of the final substrate 14, i.e. the free surface of the thin layer 2, can be protected during finishing operations, in particular the optional operation of polishing the rear face of the final substrate 14. It can be observed that during the initial steps of the method of the invention, the thin layer 2 is naturally protected by the intermediate support 12.

The final substrate 14 obtained by the above-described implementation of the invention presents an interface between the thin layer 2 and the thick layer 4 which is highly conductive both electrically and thermally since firstly depositing the material of the thick layer 4 directly onto the thin layer 2 by the method of the invention makes it possible to avoid the voids that would otherwise be formed during bonding as occurs when using prior art methods; and secondly, unlike prior art techniques, there are no intermediate layers of silicon oxide or other material of the kind that are generally used in

adhesive techniques. The method of the invention also makes it possible to omit the steps of planarizing and polishing the silicon carbide which is very hard and chemically very inert. This is particularly advantageous since problems of polishing are made worse when using polycrystalline silicon carbide since the rates of attack during polishing vary between grains or between grains and grain boundaries, and also as a function of the intrinsic and bulk crystal quality of the grains.

Nevertheless, it should be observed that in certain applications, the method of the invention can be implemented to form a thick layer 4 in which the selected materials or conditions of implementation of the method of the invention serve to obtain an interface which is a poor conductor of electricity or heat, e.g. by using an intermediate layer of insulating material between the thin layer 2 and the thick layer 4.

The first implementation of the method of the invention as described above can be the subject of numerous variants; in particular, the materials mentioned above can be substituted by using the other materials mentioned by way of example in the first row of Table 1.

In this first implementation of the method of the invention, it is also possible to substitute the step 400 of eliminating the bonding layers 10 and 11 by chemical etching, by an operation of separating the intermediate support 12 and the thin layer 2 comprising a prior operation of implanting atomic species in the intermediate support 12, for example, and/or applying mechanical stresses. It is also possible to facilitate the step 400 of eliminating the bonding layers 10 and 11 and/or separating the intermediate support 12 from the thin layer 2 by techniques known to the person skilled in the art, such as forming channels in the bonding layers 10 and 11, etc.

It is also possible to implement the method of the invention as described above without using an intermediate support 12. This applies in particular if the transferred thin layer 2 is sufficiently thick and is made of a material that is sufficiently strong. Thus, a thin layer 2 of silicon carbide having a thickness of a few tens of microns can have sufficient mechanical strength.

It should also be observed that the polarity of the thin layer 2 of silicon carbide taken from the source substrate 6 can be selected as a function of the polarity of the initial source substrate 6. The polarity of a silicon carbide substrate corresponds to the Si face or to the C face and is a concept which is well known to the person skilled in the art. Possibly, the thin layer 2 can be taken from the source substrate 6 by applying two transfers thus making it possible to change polarity twice.

It is also possible to provide an operation consisting in forming an intermediate layer, e.g. an insulating layer, on the thin layer 2 before depositing the thick layer 4. By way of example, the intermediate layer can be a fine oxide (500 angstroms (Å) thick). This provides, for example, an SiC substrate on insulation, constituted by a thin layer 2 of SiC on a fine intermediate layer of silicon oxide, with both layers then being located on a thick layer 4 of polycrystalline silicon, for example.

A second example of the first implementation of the method of the invention is described below. By way of example, it corresponds to making a substrate of gallium nitride, for optoelectronic applications in particular.

EXAMPLE 2

This second example corresponds to the second line of Table 1, and comprises the following steps which are shown in Figure 2:

· depositing a thin layer 2 of monocrystalline gallium nitride on a source substrate 6 of monocrystalline silicon carbide by metal organic chemical vapor deposition (MOCVD) or by molecular beam epitaxy (MBE);

· depositing a bonding layer 10 of silicon oxide on the thin layer 2;

· depositing a bonding layer 11 of silicon oxide on an intermediate support 12 of polycrystalline silicon carbide;

· 100, putting the two bonding layers 10 and 11 into contact with each other, and bonding the bonding layers 10 and 11 together;

· 200, detaching the thin layer 2 of gallium nitride from the source substrate 6 via the interface between the thin layer 2 and the source substrate 6 (e.g. by applying mechanical stresses) or via a zone of weakness made, for

example, by implanting atomic species in the monocrystalline silicon carbide of the source substrate 6 or in the gallium nitride of the thin layer 2;

· 300, depositing a thick layer 4 of polycrystalline silicon carbide by CVD onto the free surface of the thin layer 2; and

· 400, separating the intermediate support by eliminating the bonding layers 10 and 11, e.g. in a bath of hydrofluoric acid or merely by removing material (by eliminating the intermediate support 12 and the bonding layers 10 and 11 using the so-called "Etch-back" technique) or indeed by fracturing the bonding layers 10 and 11 via a pre-weakened zone or otherwise, or by using any other technique known to the person skilled in the art and enabling a substrate to be separated into two portions in a predetermined zoned by applying a mechanical, thermal, chemical, electrostatic, etc. stress.

Other variants of Example 2 can be envisaged. Thus, the operation 300 of depositing polycrystalline silicon carbide can be replaced by chemical vapor deposition of polycrystalline aluminum nitride or polycrystalline gallium nitride or by forming a diamond layer in order to form the thick layer 4.

In another variant, the polycrystalline gallium nitride of the thick layer 4 is formed by high pressure VPE.

In yet another variant, the polycrystalline silicon carbide of the intermediate support 12 is replaced by aluminum nitride or sapphire; a thick layer 4 of polycrystalline aluminum nitride is then deposited 300 by CVD prior to eliminating 400 the bonding layers 10 and 11.

In yet another variant, the method is the same as in one of the variants of Example 2, except that a thin layer 2 is taken which comprises not only the layer of gallium nitride, but also a layer of the underlying silicon carbide of the source substrate 6. This can be done by forming a weak layer at a certain depth in the source substrate 6, e.g. by implanting atomic species. Under such circumstances, in yet another variant, not only are the bonding layers 10 and 11 eliminated, but the portion of the thin layer 2 that is made of silicon carbide is also eliminated, if two transfers are performed on the thin layer 2, i.e. an extra transfer before placing it on the intermediate support 12.

In yet other variants, the layer of gallium nitride constituting the thin layer 2 is replaced by aluminum nitride or some other material or indeed by a stack of different materials, possibly together with other intermediate compounds.

A third example of the first implementation of the method of the invention is described below.

EXAMPLE 3

This example corresponds to making monocrystalline silicon substrates of large diameter. These substrates are expensive since they are difficult to make. As for monocrystalline silicon carbide substrates, it is advantageous to make a thin layer of monocrystalline material on a support of poorer quality, for example of a material that is polycrystalline, amorphous, or otherwise. If the thin layer is bonded directly onto a support, then there will be polishing difficulties, planarizing difficulties, phsyico-chemical difficulties at the adhesive interface, degassing difficulties, etc. The method of the invention advantageously makes it possible to avoid those difficulties, the support being made by directly depositing a thick layer 4 that forms a support on one of the faces of the thin layer 2.

As mentioned above, the method of the invention makes it possible to provide an interface of very good quality.

Advantageously, doping is performed, possibly varying as a function of depth while the thick layer 4 is being deposited so as to enhance the electrical and thermal transparency of the interface.

In this third example which corresponds to the third row of Table 1, the following steps are performed:

· a thin layer 2 of monocrystalline silicon is made on insulation (bonding layer 10 and/or 11), on an intermediate support 12;

· a thick layer 4 of polycrystalline silicon is formed 300 on the thin layer 2 so as to have a thickness of at least 725 μm;

· 400, the intermediate support 12 is separated and recovered;

· physico-chemical treatment is performed by selective etching of silicon/silicon oxide (e.g. using hydrofluoric acid) and/or mechanical removal operations are performed so as to ensure that the surface zone of the silicon in the thin layer 2 is of good quality; and

· forming operations are performed on the planeness, the thickness, the edges, etc. (polishing, lapping, shaping the edges, chemical treatment of the final substrate 14 in order to make it comply with standards such as SEMI or JEIDA, for example).

As already described above, the step of making a substrate of silicon on insulation can be performed by implanting atomic species in a zone of weakness 8 in a silicon source substrate 6 and in forming a silicon oxide bonding layer 10 on the source substrate 6, and also in forming another silicon oxide bonding layer 11 on the intermediate support 12 of silicon which can be polycrystalline or even monocrystalline, and then in putting 100 the bonding layers 10 and 11 into contact and bonding them together prior to detaching the thin layer 2 from the source substrate 6.

This step of making a substrate of silicon on insulation can be performed by a Smart-Cut® technique, for example (see French patent No. FR 2 681 472, for example).

After the thick layer 4 has been formed, the silicon on insulation substrate must be removed; this can be done using any known technique suitable for detaching the thin layer 2 of silicon from the source substrate 6. One such technique can be the technique known as the "lift-off" technique, whereby the buried silicon oxide is eliminated (e.g. the bonding layers 10 and 11). Another technique can make use of mechanical stress. Instead of using the above-mentioned lift-off technique, it is also possible to use mechanical, thermal, electrostatic, etc. stresses in order to separate the two parts situated on either side of an adhesive interface, an epitaxial interface, a porous zone, a pre-weakened zone, etc.

The intermediate support 12 can be separated via the first adhesive interface or via any one of the adhesive interfaces between the bonding layers 10 and 11 and the intermediate support 12, or if an additional step of

implanting atomic species (e.g. hydrogen) is performed, in the bonding layers 10 and 11, in the thin layer 2, or in the intermediate support 12 via the zone that is weakened by such implantation.

It will be observed that the above-mentioned forming operations can also be implemented in part or in full prior to separating the thin layer 2 from the intermediate support 12.

It should also be observed that prior to the step 300 of depositing the thick layer 4, insulation (an oxide, nitride, diamond, etc.) can be formed on the thin layer 2 so that the final substrate 14 has the structure of silicon on insulation.

In a variant of the example described above, a thick layer 4 of diamond is formed on the thin layer 2. The resulting final substrate 14 is particularly advantageous when it is necessary to have good removal of heat generated in the thin layer 2.

In a second implementation of the method of the invention, as shown in Figure 3, a thin layer 2 is formed on a thick layer 4 in the manner described above for the first implementation of the method of the invention, and then a useful layer 16 is deposited on the free face of the thin layer 2.

Table 2 below summarizes six examples of this second embodiment of the method of the invention in the context of making substrates of interest in the fields of electronics, optics, or optoelectronics.

Table 2

Useful layer 16	Thin layer 2	Intermediate support 12	Thick layer 4	Bonding layers 10, 11
GaN or AlN or AlGaN or GaInN or other	Mono SiC	Poly SiC or mono SiC (in particular if recycled)	Poly SiC or diamond or boron nitride	SiO_2 or Si_3N_4
GaN or AlN or AlGaN or GaInN or other	{111} Si	Poly SiC or mono SiC (in particular if recycled)	Poly SiC or diamond or boron nitride	SiO_2 or Si_3N_4
GaN or AlN or AlGaN or GaInN or other	Sapphire	Poly SiC or mono SiC (in particular if recycled)	Poly SiC or diamond or boron nitride	SiO_2 or Si_3N_4
GaN or AlN or AlGaN or GaInN or other	Mono SiC or {111} Si or sapphire	Poly SiC or mono SiC (in particular if recycled)	Poly AlN or diamond or boron nitride	SiO_2 or Si_3N_4
GaN or AlN or AlGaN or GaInN or other	Mono SiC or {111} Si or sapphire	Poly SiC or mono SiC (in particular if recycled)	Poly GaN or diamond or boron nitride	SiO_2 or Si_3N_4
GaN or AlN or AlGaN or other	Mono SiC or {111} Si or sapphire	Poly AlN	AlN or GaN or poly SiC or diamond or boron nitride	SiO_2 or Si_3N_4

EXAMPLE 4

In this example (1st row of Table 2) a thin layer 2 of monocrystalline silicon carbide is made on an intermediate support 12 of polycrystalline silicon carbide with bonding layers 10 and 11 of silicon oxide between them. A thick

layer 4 of polycrystalline silicon carbide is then deposited by CVD. The resulting structure is then subjected to treatment suitable for detaching the structure constituted by the thin layer 2 on the thick layer 4 from the intermediate support. By way of example this treatment consists in etching the bonding layers 10 and 11 in hydrofluoric acid, with or without mechanical stress, or merely by removing the material of the intermediate support 12 and possibly also of the bonding layers 10 and 11. Finally, a useful layer 16 of gallium nitride is deposited on the free face of the monocrystalline silicon carbide of the thin layer 2 by MOCVD. The useful layer 16 of gallium nitride is particularly suitable for optoelectronic applications.

EXAMPLE 5

In this example (second row of the above table) a structure comprising a thin layer 2 of {111} silicon is formed on an intermediate support 12 of polycrystalline silicon carbide in the manner described above and having a layer of silicon oxide between them. A thick layer 4 of polycrystalline silicon carbide is deposited on the thin layer 2 of {111} silicon by CVD. The resulting structure is then subjected to treatment in a bath of hydrofluoric acid with or without mechanical stress or any other treatment suitable for separating the thin layer 2 with the thick layer 4 from the intermediate support 12. Thereafter MOCVD is used to deposit monocrystalline gallium nitride on the free surface of the {111} silicon which is a material known for enabling good epitaxy of gallium nitride. The thickness of the {111} silicon is preferably advantageously limited to less than 1000 Å so as to enable it to accommodate without breaking to the thermal expansion that can occur during the various operations mentioned above.

EXAMPLE 6

In this element (third row of the above table) a thin layer 2 of sapphire is made on a polycrystalline silicon carbide intermediate support 12 together with bonding layers 10 and 11 of silicon oxide between them, after which a thick layer 4 of silicon carbide is deposited 300 on the thin layer 2. The

bonding layers 10 and 11 are eliminated to enable the intermediate support 12 to be recovered. Finally, a useful layer 16 of gallium nitride is deposited on the sapphire. Sapphire is another material that is known for enabling good epitaxy of gallium nitride.

EXAMPLE 7

In this seventh example (fourth row of the table above) one of the structures described in any one of the three preceding examples is made but the thick layer 4 of polycrystalline silicon carbide is replaced by a layer of polycrystalline aluminum nitride.

EXAMPLE 8

In this example (fifth row of the above table) a structure is made of the type described in any one of Examples 4 to 6 above, but the thick layer 4 of polycrystalline silicon carbide is replaced by a layer of polycrystalline gallium nitride deposited by HVPE.

EXAMPLE 9

In this example (sixth row of the above table) a structure is made as described in any one of the five preceding examples, but in which the polycrystalline silicon carbide of the intermediate support 12 is replaced by polycrystalline aluminum nitride.

In the last six examples above, the monocrystalline silicon carbide, the {111} silicon, or the sapphire is used as a substrate for gallium nitride epitaxy. The advantage of silicon carbide is that its coefficient of thermal expansion is similar to that of gallium nitride.

It should be observed that the thickness properties of the thick layer 4 can be important, for example when it is desired to make an electrical contact with the rear face of the final substrate 14 or when evacuating heat generated by components formed in the useful layer 16 is a deciding factor, or indeed

when it is desired to extract and control light emitted by a diode or a laser made in the useful layer 16.

It should also be observed that if the thin layer 2 is of a thickness and if the material constituting it is of a stiffness that are sufficient, then structures equivalent to those described above can be made without using an intermediate support 12.

Numerous other variants of this second implementation of the method of the invention are also possible. Thus, the step of forming the thick layer 4 of polycrystalline SiC, of aluminum nitride, or of gallium nitride, can be replaced by a step of forming a thick layer 4 of diamond or of boron nitride.

In other variants, the nature of the intermediate support 12 is changed. Thus, monocrystalline silicon carbide can be used (in particular when it can be recycled), to replace the polycrystalline silicon carbide or the polycrystalline aluminum nitride.

Similarly, these examples can be transposed to the situation in which a useful layer 16 of aluminum nitride, of an alloy of aluminum and gallium, or of an alloy of gallium and indium, etc. is formed in accordance with the invention instead of the useful layer 16 of gallium nitride as described above. The useful layer 16 of gallium nitride can also be a multilayer structure comprising a stack of layers of the gallium nitride, aluminum nitride, etc. type, optionally with different kinds of doping, etc.

In a third implementation of the method of the invention, as shown in Figure 4, a structure is formed in which the thick layer 4 is deposited directly on the useful layer 16, contrary to the description given above for the second implementation of the method of the invention. The useful layer 16 is itself deposited directly on the thin layer 2 after this layer has been separated from the source substrate 6.

The third implementation of the method of the invention is described below with reference to three examples.

The materials used in the context of these three examples are summarized in Table 3.

Table 3

Useful layer 16	Thin layer 2	Intermediate support 12	Thick layer 4	Bonding layers 10, 11
GaN or AlN or AlGaN or GaInN or other	Mono SiC or {111} SiC or sapphire	Poly (or mono) SiC or poly AlN or diamond or other	AlN or GaN or poly SiC or other	SiO_2 or Si_3N_4
GaN or AlN or AlGaN or GaInN or other	Mono SiC or {111} SiC or sapphire + etching	Poly (or mono) SiC or poly AlN or diamond or other	AlN or GaN or poly SiC or other	SiO_2 or Si_3N_4
+ etching a portion of the GaN or other	Mono SiC or {111} SiC or sapphire + etching	Poly (or mono) SiC or poly AlN or diamond or other	AlN or GaN or poly SiC or other	SiO_2 or Si_3N_4

EXAMPLE 10

In this example (first row of Table 3) a structure is made comprising a thin layer 2 of monocrystalline silicon carbide on an intermediate support 12 of polycrystalline silicon carbide with bonding layers 10 and 11 of silicon oxide between them, in the manner described above for the first and second implementations of the method of the invention. Thereafter, a useful layer 16 of monocrystalline gallium nitride is formed on the free surface of the thin layer 2 of silicon carbide by MOCVD. A thick layer 4 of polycrystalline silicon carbide is then deposited by CVD on the useful layer 16. The resulting structure is then subjected to a step 700 of treatment suitable for separating the structure constituted by the thin layer 2, the useful layer 16, and the thick layer 4 from the intermediate support 12. By way of example, this treatment consists in etching in hydrofluoric acid with or without mechanical stress, or merely by removing matter. This provides firstly a structure constituted by a stack comprising in succession a thick layer 4 acting as a support for a useful

layer 16 of gallium nitride, itself covered in a thin layer 2 of monocrystalline silicon carbide, and secondly the intermediate support 12 ready for recycling.

In this case, and unlike the second implementation of the method of the invention as described above, the monocrystalline gallium nitride is deposited before the thick layer 4 is formed.

EXAMPLE 11

In another example of this third implementation of the method of the invention, the structure of Example 10 is made and then the thin layer 2 of monocrystalline silicon carbide is withdrawn, e.g. by a step 800 of etching in a plasma (second row of Table 3).

EXAMPLE 12

In yet another example of this third implementation of the method of the invention (third row of Table 3), a structure of the kind described in Example 11 is made, except that not only is the layer 2 of monocrystalline silicon carbide removed, but so also is a portion of the useful layer of gallium nitride.

It can be observed that the thin layer 2 of monocrystalline silicon carbide or the useful layer 16 of monocrystalline gallium nitride can be subjected to various additional technological steps prior to being subjected to deposition of the thick layer 4, with these steps seeking to produce electronic components, in full or in part, or they can comprise making uniform deposits of additional films whether epitaxially or otherwise.

It should also be observed that the polarity of the thin layer 2 of monocrystalline silicon carbide and that of the useful layer 16 of gallium nitride can be determined by selecting the polarity of the initial source substrate 6. Optionally, the method of the invention can include at least one double transfer enabling polarity to be changed twice in succession.

Similarly, these examples can be transposed to circumstances in which the invention is used to form a useful layer 16 of aluminum nitride, or an alloy of aluminum and gallium, or of an alloy of gallium and indium, etc. instead of

the gallium nitride useful layer 16 as described above. The gallium nitride useful layer 16 can also be constituted by a multilayer structure comprising a stack of layers of the gallium nitride, aluminum nitride, etc. types, possibly with doping of different kinds, etc.

In other variants, the nature of the intermediate support 12 is changed. Thus, monocrystalline silicon carbide is used (in particular when the intermediate support is recycled), or else use is made of diamond or some other material to replace the polycrystalline silicon carbide or the aluminum nitride.

In a fourth embodiment of the method of the invention, as shown in Figure 5, a useful layer 16 is deposited on a thin layer 2 itself located on an intermediate support 12, prior to separating the intermediate support 12 from the structure constituted by the thin layer 2 and the useful layer 16 and proceeding to deposit the thick layer 4 on the thin layer 2 or on the useful layer 16, i.e. on one side or the other of the structure constituted by the thin layer 2 and the useful layer 16.

This fourth implementation of the method of the invention is illustrated by two examples.

EXAMPLE 13

In this example, the following steps are performed:

· forming firstly a structure constituted by a thin layer 2 of monocrystalline silicon carbide on a source substrate 6 with a zone of weakness 8, and secondly, an intermediate support 12 with bonding layers 10 and 11 between them, e.g. as described above for the first implementation;

· detaching the thin layer 2 from the source substrate 6 via a zone of weakness 8 (e.g. obtained by implanting performed in the source substrate 6 prior to being put into contact with the intermediate support 12);

· depositing a useful layer 16 of monocrystalline gallium nitride on the free surface of the thin layer 2 of silicon carbide;

· detaching the assembly constituted by the thin layer 2 and the useful layer 16 from the intermediate support 12 (e.g. by treatment in a bath of hydrofluoric acid); and

· depositing a thick layer 4 of polycrystalline silicon carbide on the free surface of the useful layer 16.

EXAMPLE 14

In this example, the procedure is the same as in the preceding example, except that the step of depositing the thick layer 4 on the useful layer 16 is replaced by a step of depositing the thick layer 4 on the thin layer 2.

As mentioned above, if the thickness and the strength of the thin layer 2 together with the useful layer 16 make this possible, then the implementations described above can be implemented without using an intermediate support 12 at any time in the method, or without using an intermediate support 12 while depositing the thick layer 4, but then using a temporary support which serves as a stiffener during the step of separating the thin layer 2 from the source substrate 6, the temporary support being removed before depositing the thick layer 4.

The fifth implementation corresponds to methods of the invention during which no use is made either of an intermediate support 12 or of a temporary support of the kind described above.

A few examples of this implementation of the method of the invention without an intermediate support 12 are shown in Figure 6.

Thus, starting from a source substrate 6 in which a zone of weakness 8 has been produced (e.g. by implanting atomic species), it is possible either to separate the thin layer 2 directly, or else to deposit a useful layer 16 thereon prior to separating the thin layer 2 from its source substrate 6, via the zone of weakness 8.

In the first case, the thick layer 4 is deposited on the thin layer 2 (thus reproducing the final substrate 14 of Example 1, for example). This technique can optionally be continued by depositing a useful layer 16 on the face of the

thin layer 2 which is opposite from its face that has received the thick layer 4 (thus reproducing the final substrate 14 of Example 4, for example).

In the second case, the thick layer 4 is deposited on the same side as the thin layer 2 (thus reproducing the final substrate 14 of Example 4) or on the same side as the useful layer 16 (thus reproducing the final substrate 14 of Example 10). Optionally, as described with reference to Figure 4 (see step 800), it is then possible to remove the thin layer 2 (thus reproducing the final substrate of Example 11, for example).

Numerous variants of the implementations described above can also be envisaged without going beyond the ambit of the invention.

For example, the various operations described in the examples illustrating the implementations of the method of the invention can be combined.

Thus, as shown in Figure 7, one variant consists in batch processing the thin layers 2 as obtained prior to depositing the thick layer 4. Under such circumstances, the thin layers 2 are fixed on a single intermediate support 12 of large size.

The shape of this single intermediate support 12 can be arbitrary (circular, rectangular, etc.).

Under such circumstances, the thin layers 2 can be identical or they can be different. Each of the thin layers 2 can be subjected to a separate operation of detaching the thin layer from the intermediate support 12. By way of example, the single intermediate support 12 can be a plate of polycrystalline silicon carbide covered in a silicon oxide.

After the thick layer 4 has been deposited, the assembly comprising the single intermediate support 12 and the associated thin layers 2 and thick layers 4 is subjected to a lift-off operation in a bath of hydrofluoric acid. Each individual intermediate support 12 is recycled.

In yet another variant of the implementations described above, a thick layer 4 is deposited on a surface that is larger than the surface corresponding to the main faces of the thin layer 2. This variant is shown in Figure 8.

In this variant, a structure is made constituted by a thin layer 2 on an intermediate support 12 with bonding layers 10 and 11 between them, of the kind made in the first implementation described above. This structure is then placed in a sample carrier 20 in such a manner that the free surface of the thin layer 2 is flush with the surface of the sample carrier 20 (see Figure 8a). A thick layer 4 is then formed on said free surface and overflows onto the sample carrier 20.

The substrate formed in this way can optionally be subjected to treatment suitable for eliminating the projecting edges of the thin layer 2. The edges of a deposited layer generally present irregularities, defects, beading, etc. The present variant makes it possible to eliminate such edges.

This variant is also advantageous for forming a substrate of diameter greater than that of the thin layer 2 and adapted to a line for processing substrates of a given diameter, even though the thin layer 2 cannot be formed directly with said diameter.

This variant is also advantageous when, during formation of a single thick layer 4 on a plurality of thin layers 2, a single support is made for a plurality of thin layers 2 and/or useful layers 16 (see Figure 8b). This variant can also be implemented by forming a thick layer 4 on each of the assemblies constituted by an intermediate support 12 and by a thin layer 2 and placed on a plane sample carrier. The thick layer 4 then drops back onto the edges of the thin layer 2.

A variant of the method of the invention is mentioned above which consists in optimizing the parameters for depositing the thick layer 4 so as to make a thick layer 4 as a single crystal.

Even if the quality of such a monocrystalline thick layer 4 is not good, it can be good enough for numerous applications, for which crystal quality needs to be very high only in the surface layer 2 or 16.

Such variants of the method of the invention are particularly advantageous when it is not possible to grow single crystals (as is the case for gallium nitride) or when it is expensive to grow single crystals (as is the case for monocrystalline silicon carbide).

It is possible to perform chemical vapor deposition of a thick layer 4 of silicon carbide on a surface layer 2 or 16 which then acts as a seed for seeding the growth of the thick layer 4, while still using very high rates of growth (several tens to several hundreds of microns per hour).

It will be observed that in prior art techniques, thin layers 2 are often grown on a support by epitaxy. Under such circumstances, the substrate must be of very good quality so as to ensure that the thin layer grown epitaxially thereon is likewise of very good quality, i.e. so as to ensure that defects are not transferred.

In the method of the invention, the support, i.e. the thick layer 4, can be made at lower cost since it is a support whose quality can often be inferior, particularly since it is not necessarily used for restarting epitaxial growth.

In other variants, the above description is transposed to other semiconductors such as indium phosphide and gallium arsenide, or indeed to other materials such as lithium niobate.

In yet other variants, an intermediate layer, e.g. an insulating layer is made between the thin layer 2 and/or the useful layer 16, and the thick layer 4 or indeed the thin layer 2 and the useful layer 16. By way of example, this intermediate layer can be made of diamond or of fine oxide (500 Å thick), etc.

CLAIMS

1/ A method of fabricating a substrate comprising a thin layer carried by a layer constituting a mechanical support, in particular for optics, electronics, or optoelectronics, the method comprising the following steps:

· detaching a layer of material for forming the thin layer (2) from a source substrate (6); and then

· making a thick layer (4) on the thin layer (2) by depositing material to form the layer which constitutes the mechanical support.

2/ A method according to claim 1, characterized by the fact that the thick layer (4) is deposited progressively, on the thin layer, by a technique taken from the list comprising: chemical vapor deposition, liquid deposition, molecular beam deposition.

3/ A method according to any preceding claim, characterized by the fact that it includes an operation consisting in depositing a useful layer (16) on one of the faces of the thin layer (2).

4/ A method according to claim 3, characterized by the fact that it includes an operation consisting in depositing a useful layer (16) on the other face of the thin layer (2).

5/ A method according to claim 3 or claim 4, characterized by the fact that at least one useful layer (16) is deposited before the thick layer (4) is formed.

6/ A method according to any one of claims 3 to 5, characterized by the fact that at least one useful layer (16) is deposited after the thick layer (4) has been formed.

7/ A method according to any one of claims 3 to 6, characterized by the fact that the useful layer is constituted by a material having a large band gap,

taken from the list comprising: gallium nitride, aluminum nitride, and compounds of at least two elements taken from the list comprising aluminum, indium, and gallium.

8/ A method according to any one of claims 3 to 7, characterized by the fact that each of the useful layer (16) and the thick layer (4) is deposited on a different face of the thin layer (2).

9/ A method according to any preceding claim, characterized by the fact that the thin layer (2) is constituted by a monocrystalline material.

10/ A method according to any preceding claim, characterized by the fact that the thick layer (4) is formed by depositing a material taken from the list constituted by: monocrystalline materials, polycrystalline materials, amorphous materials, materials comprising a plurality of phases, and materials that are less expensive than those constituting the thin layer.

11/ A method according to any preceding claim, characterized by the fact that it includes a step of transferring the thin layer (2) onto an intermediate support (12) prior to forming the thick layer (4) on the thin layer (2).

12/ A method according to claim 11, characterized by the fact that the intermediate support (12) supports a plurality of thin layers (2).

13/ A method according to claim 11 or claim 12, characterized by the fact that it includes an operation which consists in eliminating the intermediate support (12).

14/ A method according to claim 13, characterized in that the intermediate support (12) is eliminated by separating the thin layer (2) from the intermediate support (12), in particular to enable the intermediate support to be recycled.

15/ A method according to any preceding claim, characterized by the fact that it includes an operation of forming a bonding layer (10) on the thin layer (2) before it is detached from the source substrate (6).

16/ A method according to any one of claims 11 to 14, characterized by the fact that it includes an operation of forming a bonding layer (11) on the intermediate support (12) before transferring the thin layer (2) thereon.

17/ A method according to claim 15 or claim 16, characterized by the fact that the bonding layer (10, 11) is made of a material taken from the list comprising: amorphous materials, polycrystalline materials, and metallic materials.

18/ A method according to any preceding claim, characterized by the fact that the thin layer (2) is constituted by a material taken from the list comprising: silicon, silicon carbide, sapphire, diamond, gallium nitride, aluminum nitride, and a combination or a superposition of at least two of these materials.

19/ A method according to any preceding claim, characterized by the fact that the thick layer (4) is made of a material taken from the list comprising: silicon, silicon carbide, sapphire, diamond, graphite, gallium nitride, aluminum nitride, and a combination or a superposition of at least two of these materials.

20/ A method according to any preceding claim, characterized by the fact that the thin layer (2) is detached from the source substrate (6) via a zone of weakness (8).

21/ A method according to claim 20, characterized by the fact that the zone of weakness (8) is made by implanting atomic species in the source substrate (6) close to a determined depth.

22/ A method according to any one of claims 1 to 19, characterized by the fact that the thin layer (2) is detached from the source substrate (6) by eliminating a zone interposed between the thin layer (2) and the remainder of the source substrate (6), for example by chemical etching.

23/ A method according to any preceding claim, characterized by the fact that the conditions under which the thick layer (4) is deposited are optimized so that the thick layer corresponds to monocrystalline quality.

24/ A method according to any preceding claim, characterized by the fact that the conditions under which the thick layer (4) is deposited are optimized so that it corresponds to a particular quality taken from the list comprising the following qualities: monocrystalline, polycrystalline, insulating, and conductive.

25/ A method according to any preceding claim, characterized by the fact that the thick layer (4) is formed by using the thin layer (2) as a seed layer for forming said thick layer (4).