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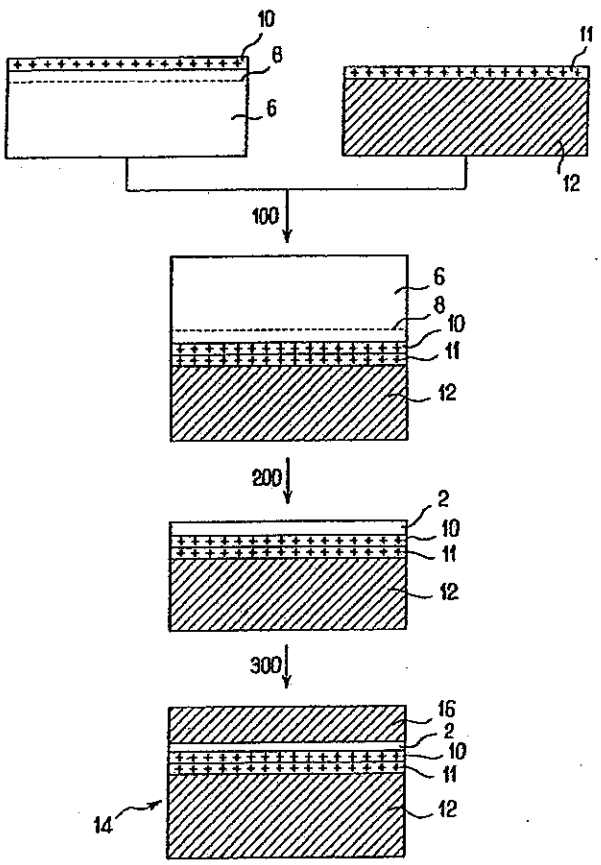
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(54) Title: METHOD FOR MAKING A SUBSTRATE IN PARTICULAR FOR OPTICS, ELECTRONICS OR OPTOELECTRONICS AND RESULTING SUBSTRATE

(54) Titre : PROCEDE DE FABRICATION D'UN SUBSTRAT NOTAMMENT POUR L'OPTIQUE, L'ELECTRONIQUE OU L'OPTOELECTRONIQUE ET SUBSTRAT OBTENU PAR CE PROCEDE



(57) **Abstract:** The invention concerns a method for making substrates, in particular for optics, electronics or optoelectronics. The method comprises steps which consist in: transferring a seed layer (2) onto a support (12) by molecular adhesion at the bonding interface; epitaxial growth of a useful layer (16) on the seed layer, and applying stresses to produce removal of the formed assembly from the seed layer (2) and the useful layer (16) relative to the support (12) at the bonding interface.

(57) **Abrégé :** L'invention concerne un procédé de fabrication de substrats, notamment pour l'optique, l'électronique ou l'opto-électronique. Le procédé comprend les étapes suivantes : report d'une couche germe (2) sur un support (12) par adhésion moléculaire au niveau d'une interface de collage, épitaxie d'une couche utile (16) sur la couche germe, et application de contraintes pour conduire au détachement de l'ensemble constitué de la couche germe (2) et de la couche utile (16) par rapport au support (12) au niveau de l'interface de collage.

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METHOD FOR MAKING A SUBSTRATE IN PARTICULAR FOR OPTICS, ELECTRONICS OR OPTOELECTRONICS AND RESULTING SUBSTRATE

Field Of The Invention

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 suitable for use in fabricating light-emitting and laser diodes.

Background

For use in optics, electronics, or optoelectronics, it is often desired to obtain substrates that include a thin working layer. Two broad families of methods are known for making such substrates for such purposes. These families are those comprising methods in which a thin layer taken from a source substrate is transferred and placed on a support substrate, and methods in which the thin layer is deposited on a support substrate by a deposition technique such as molecular beam epitaxy (MBE), metal organic chemical vapor deposition (MOVCD), etc. Nevertheless, there exist materials that are not available or that are very difficult to obtain in the form of a source substrate from which a thin layer can be taken, and/or whose growth by deposition on a support substrate is not yet satisfactory. This applies in particular to monocrystalline gallium nitride which is not available in the form of a solid single crystal of quality and/or diameter that are satisfactory and/or at reasonable price, and as a result it can be grown only by a heteroepitaxial technique.

Furthermore, with known techniques for growing a working layer on a seed layer itself carried by a support, there is often a need to remove the support in question in order to obtain the final product.

There are various techniques that are known for doing this. Thus, document FR 2 787 919 A describes eliminating such a substrate by a mechano-chemical thinning technique. Nevertheless, all techniques of

eliminating the support by etching or some equivalent technique are undesirable since they lead to significant losses of material and that can sometimes be expensive.

Document US 6 114 188 A describes a technique for separating a complex transition metal oxide (CTMO) film made by deposition, in which a special treatment is performed on the native substrate from which the film is to be grown, and then the deposited film is detached from the native substrate. Nevertheless, that technique is undesirable since it runs the risk of compromising proper starting of film growth and of leading either to a loss of yield or to a deposited layer of poor quality.

The present invention seeks to mitigate those drawbacks.

Summary Of The Invention

To this end, the invention provides a method of fabricating substrates, in particular for optics, electronics, or optoelectronics, the method being characterized by the fact that it comprises the following steps:

- transferring a seed layer onto a support by molecular adhesion in an adhesion interface;
- growing a working layer epitaxially on the seed layer; and
- applying stresses to cause the assembly constituted by the seed layer and the working layer to become detached from the support at the adhesion interface.

The stresses applied to perform separation may be taken from the group comprising: mechanical stresses, thermal stresses, electrostatic stresses, and laser irradiation stresses.

Furthermore, and in order to return to gallium nitride, it is known that sapphire and silicon carbide can constitute good seed substrates for heteroepitaxy for this material. However, sapphire is an electrical insulator, which is a disadvantage in certain applications, and monocrystalline silicon carbide

presents the drawbacks of being expensive and difficult to obtain in large diameters. For gallium nitride, an ideal substrate for heteroepitaxy would be {111} silicon. This substrate is considered to be ideal since it is a material in very widespread use (and thus suitable for numerous substrate processing systems in which this material is already in use), it is not very expensive, and it is available in large diameters. However, when attempts have been made to deposit gallium nitride on {111} silicon using the standard technique of MOCVD at 1000°C to 1100°C approximately, they have encountered a problem of dislocations forming in the thin layer of gallium nitride at a concentration in excess of 10^8 per square centimeter (cm^2), and even of said thin layer cracking.

One embodiment provides a method that enables working thin layers to be obtained that are of quality that is better than that of the layers obtained in prior art methods, in particular for materials that are not available or that are very difficult to obtain in the form of a source substrate from which it is possible to take a thin layer, or materials that cannot yet be grown in satisfactory manner by being deposited on a support substrate. The quality of the working thin layers in question may be assessed in particular and above all in terms of cracking and secondarily in terms of dislocation concentration.

The support may be constituted by a material whose coefficient of thermal expansion is 0.7 to 3 times the coefficient of the working layer, and the seed layer is suitable for accommodating the thermal expansion of the support and of the working layer.

Preferably, the values of the thermal expansion coefficients considered in this document may relate to those in a plane parallel to the plane of the working layer.

By means of this feature, the material selected to form the support presents thermal expansion coefficients that can reduce or even eliminate significant tension or compression stresses of the kind that arise during the variations in temperature that are inherent to growing the working layer, or that occur on returning the substrate formed in this way to ambient temperature.

It should be observed, in particular with reference to problems of cracking, that tolerance relative to differences between the thermal expansion coefficients of the respective materials of the working layer and of the support may increase when said difference leads to compression in the working layer as opposed to when it leads to stretching of said layer. Thus, in compression, the thermal expansion coefficient of the support material can be several times greater than that of the working layer. However, in extension, the thermal expansion coefficient of the support material may preferably not be less than 0.7 times the coefficient of the working layer.

It should be observed that the seed layer can be suitable for adapting to the thermal expansions imposed by the support and/or the working layer. For this purpose, the seed layer can be of a thickness that is small enough to enable it to be deformable so as to follow the dimensional variations due to thermal expansion of the support and/or of the working layer. This thickness may depend on the material constituting the seed layer and on the respective materials of the support and of the working layer. Typically, for a silicon carbide support having thickness of 300 microns (μm) and a gallium nitride working layer having thickness of several microns, a monocrystalline silicon carbide seed layer can have thickness that is less than 0.5 µm, and that may preferably be less than 1000 angstroms (Å).

Advantageously, the material constituting the seed layer can also present lattice parameters such that the working layer can be grown epitaxially on the seed layer

with dislocations in the working layer at a concentration of less than $10^7/cm^2$. The person skilled in the art knows how to perform such epitaxial growth by selecting parameters and orientations both for the seed layer and for the working layer.

By way of example, Table 1 below summarizes the lattice parameters and the thermal expansion coefficients of various materials that are suitable for use in implementing the method of the invention, either as a material for the working layer or as a material for the seed layer or as a material for the support substrate.

Table 1

	GaN (W)	AlN (W)	Al_2O_3 (H)	Si (C)	6H-SiC (W)
Lattice parameters (Å)	a = 3.189 c = 5.185	a = 3.112 c = 4.982	a = 4.758 c = 12.99	c = 5.430	a = 3.08 c = 15.12
Thermal expansion coefficients along a or c ($\times 10^{-6} K^{-1}$)	5.59 3.17	4.15 5.27	7.5 8.5	2.6	4.20 4.68
Thermal conductivity (W/cm.K)	1.3	2.5	0.5	1.5	4.9
Maximum diameter currently available (inches)			4	8	2
Quality of substrates available			Excellent	Excellent	Variable
Relative prices for 2-inch substrates (arbitrary units)			10	1	125

The method can particularly be advantageous when it is desired to form a working layer out of gallium nitride. To do this, the prior art proposes various techniques suffering from drawbacks that the invention makes it possible to overcome.

Thus, in prior art techniques, a substrate was used made of monocrystalline silicon carbide or of sapphire to

serve both as a support and as a growth seed for the working layer. However, when the working layer is used to form light-emitting diodes (LEDs), using a solid silicon carbide or sapphire support means that it is not possible in satisfactory manner to control the positions of electrical contacts, the extraction of the light emitted by the diode, or the use of a reflecting surface, etc. In the present case, a first support can be selected that is suitable for the deposition operation, and that can also be recovered, and then a second support can be selected which is fitted after the first support has been removed that is suitable for achieving better control over the above-mentioned aspects. Furthermore, substrates made of monocrystalline silicon carbide, and to a lesser extent of sapphire, are expensive and of limited diameter, whereas in the present case a seed layer is used which can be thin and taken from a substrate which is optionally recyclable or from a single crystal, thus making it possible to save consumption of a material that can be expensive. Furthermore, the method can make it possible to use a seed layer which is constituted by a material that is easier to obtain in large diameters than is monocrystalline silicon carbide, for example.

Furthermore, sapphire is an electrical insulator, so if it is retained in the form of a solid support, then it becomes necessary for any electrodes needed for the intended application of the working layer to be provided solely on the working layer itself, which can give rise to problems of available space (for example if two electrical contacts are to be made on a front face, i.e. on the free surface of the working layer).

The method can make it possible to decorrelate the properties that are desired for forming a growth seed for the working layer and the properties that are desired for the support, particularly when the support is eliminated

with the possibility of being recycled, thus making it possible to mitigate the drawbacks mentioned above.

In other prior art techniques, attempts have been made to deposit gallium nitride directly on solid gallium nitride or indeed on neodymium gallate or on indium gallate. However, solid gallium nitride is expensive and those techniques are not mature.

In other prior art techniques mentioned above, a working layer of gallium nitride has been deposited on {111} silicon. However, if {111} silicon is used as a support, i.e. in thick form, then cracking is observed in the working layer because of poor matching in terms of thermal expansion. By decorrelating selections, the method can make it possible firstly to select a seed layer that is suitable for nucleation and that is sufficiently thin to deform under the effect of thermal stresses, and secondly to select a thick layer that is matched in terms of thermal expansion to the working layer which is caused to grow on the seed layer.

Advantageously, the method may include the following characteristics taken separately or in combination:

· at least one bonding layer is interposed between the seed layer and the support, the adhesion interface involving the or each bonding layer;

· the working layer is constituted by a material taken from the list comprising: gallium nitride, aluminum nitride, and gallium and aluminum nitride (and in general manner, semiconductive nitrides having a large band gap);

· the seed layer comprises a material taken from the list comprising: sapphire, silicon carbide, zinc oxide, and {111} silicon;

· the seed layer is selected to obtain a precise crystal structure and orientation, for example to obtain hexagonal or cubic gallium nitride, or if an Si face or a C face is selected to deposit the working layer on a seed layer of silicon carbide;

· the seed layer is made of gallium nitride of very high quality, i.e. having fewer than 10^6 dislocations per square centimeter, e.g. gallium nitride obtained by the epitaxial lateral overgrowth (ELOG) technique;

· the support comprises a material taken from the list comprising: amorphous materials, polycrystalline materials, and sintered materials;

· the support comprises a material taken from the list comprising: polycrystalline silicon carbide, monocrystalline silicon carbide, polycrystalline aluminum nitride, polycrystalline gallium nitride, and monocrystalline gallium nitride having a high concentration of dislocations (greater than $10^7/cm^2$);

· the seed layer is of the same chemical composition as the support;

· the seed layer is taken from a source substrate, by dissociating the seed layer from the source substrate at a pre-weakened zone;

· the seed layer is taken from a source substrate assembled to the support and then eroded via its free face so as to obtain a seed layer of desired thickness (for this purpose it is possible to use a technique taken from the technique used for obtaining substrates and of the type known in the art as bond and etch back silicon on insulator (BESOI));

· the pre-weakened zone is made by implanting atomic species in the source substrate at a depth which corresponds to the thickness of the seed layer (ignoring finishing steps); and

· the seed layer is dissociated from the source substrate at least in part by an operation taken from the list comprising: heat treatment, applying mechanical stresses, and chemical etching, or a combination of at least two of these operations.

Above and in the remainder of this document, "atomic implantation" is used to cover any bombardment using atomic or ionic species and suitable for introducing

these species into a material so as to achieve a concentration maximum of these species in the material, said 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 in the material using an ion beam implanter, a plasma immersion implanter, etc. The term "atomic or ionic species" is used to mean an atom in ionic, neutral, or molecular form, or molecules in ionic or neutral form, or indeed a combination of different atoms or molecules in ionic or neutral form.

Brief Description Of The Drawings

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 of the invention; and
- Figure 4 is a diagrammatic perspective view of an intermediate support with four seed layers, of the kind that can be used in a variant of the method of the invention.

Detailed Description

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

In a first implementation, shown in Figure 1, a final substrate 14 is made comprising a working layer 16 on a seed layer 2, 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 having atomic species implanted therein, forming a layer of amorphous material on a surface of a support 12 to make another bonding layer 11;

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

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

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

· 300, depositing a working layer 16 on the surface of the seed layer 2 corresponding to the zone of weakness 8.

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

Examples of the step of implementing atomic species and the step 200 of detaching the seed layer 2 are described in French patent No. FR 2 681 472, for example.

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

Between steps 200 and 300, the method of the invention optionally includes operations of preparing the surface of the seed layer 2 that is to receive the working layer 16. The preparation operations comprise, for example, polishing operations, annealing operations, smoothing annealing operations (e.g. under hydrogen), annealing operations for reinforcing the adhesive interface between the bonding layers 10 and 11, sacrificial oxidation operations (oxidation followed by elimination of the oxidized material), etching operations, etc.

This first implementation of the method of the invention is described in detail with reference to five

particular but non-limiting examples that are described below one after another, with the way in which detaching is performed at the adhesive interface provided in these examples being described after Example 5.

Table 2 below summarizes examples of materials that are suitable for use in implementing the first implementation described above.

Table 2

Working layer 16	Seed layer 2 (typically 1000 Å thick)	Bonding layers 10, 11 (typically 1 μm thick)	Support 12 (typically 300 μm thick)
GaN or AlN or AlGaN or GaInN or SiC or other	Mono SiC	SiO_2 or Si_3N_4	Poly SiC or mono SiC or sapphire or poly AlN or poly GaN
GaN or AlN or AlGaN or GaInN or SiC or other	{111} Si	SiO_2 or Si_3N_4	Poly SiC or mono SiC or sapphire or poly AlN or poly GaN
GaN or AlN or AlGaN or GaInN or SiC or other	Sapphire	SiO_2 or Si_3N_4	Poly SiC or mono SiC or sapphire or poly AlN or poly GaN
GaN or AlN or AlGaN or GaInN or SiC or other	Mono GaN	SiO_2 or Si_3N_4	Poly SiC or mono SiC or sapphire or poly AlN or poly GaN

GaN or AlN or AlGaN or GaInN or SiC or other	$NdGaO_2$ or $LiGaO_3$	SiO_2 or Si_3N_4	Poly SiC or mono SiC or sapphire or poly AlN or poly GaN

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

EXAMPLE 1

In the example corresponding to the first row of Table 2, a working layer 16 is made of gallium nitride on a seed layer 2 constituted by monocrystalline silicon carbide, itself on a polycrystalline silicon carbide support 12, with bonding layers 10 and 11 of silicon carbide being interposed between the support 12 and the seed layer 2.

By way of example, the seed layer 2 is 1000 Å thick. The support 12 is 300 μm thick, for example.

The structure constituted by the stack of the seed layer 2 of monocrystalline silicon carbide, the two bonding layers 10 and 11 of silicon oxide, and the support 12 of polycrystalline silicon carbide is made by a layer transfer method known to the person skilled in the art (e.g. see an application of the Smart-Cut® method in French patent No. FR 2 681 472).

The working layer 16 can be made by chemical vapor deposition (CVD), by high temperature chemical vapor deposition (HTCVD), by MOCVD, by MBE, or by hydride vapor phase epitaxy (HVPE), see for example the documents "GaN bulk substrates for GaN-based LEDs and LDs", by O. Oda et al., Phys. Stat. Sol. (a), No. 180, p. 51 (2000), or other equivalent techniques.

The use of silicon oxide for the bonding layer 10 makes it easier to take the seed layer 2 from the source substrate 6. The planarized deposit of silicon oxide

makes it possible to eliminate surface irregularities and to perform a polishing step, a planarizing step, a cleaning step, a chemical preparation step, and a step of bonding said silicon oxide onto the silicon oxide of the bonding layer 11 formed on the support 12 using conventional techniques that are easy to implement. By way of example, the set of bonding layers 10 and 11 is one micron thick.

EXAMPLE 2

In this example (second row of above table), a structure is provided that is equivalent to that of Example 1, except that the seed layer 2 of silicon carbide is replaced by a seed layer 2 of {111} silicon.

The thickness of the {111} silicon is preferably limited to less than 3000 Å so as to enable it to adapt without cracking to the thermal expansion that will take place during the various operations mentioned above.

EXAMPLE 3

In this example (third row of the above table), a structure is made that is equivalent to that of Examples 1 and 2, except that the seed layer 2 is made of sapphire.

Sapphire is another material that is known for permitting good epitaxy of gallium nitride.

EXAMPLE 4

In this example (fourth row of the above table) a structure is made that is equivalent to that of Examples 1 to 3, except that the seed layer 2 is made of monocrystalline gallium nitride.

EXAMPLE 5

In this example (fifth row of the above table), a structure is made that is equivalent to that of

Examples 1 to 4, except that the seed layer 2 is made of neodymium gallate or of lithium gallate.

Numerous variants of the above examples can be envisaged.

Thus, the silicon oxide in one of the bonding layers 10 and 11, or the silicon oxide in both bonding layers 10 and 11 can 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 advantageous in the context of optimizing deposition of the working layer 16 in order to form a monocrystalline layer of good quality or indeed when it is desired to increase the rate of deposition. Silicon nitride also has the advantage of limiting or even avoiding diffusion of gallium into the support 12.

In yet another variant of this first implementation of the method of the invention, the working layer 16 of gallium nitride is replaced by a working layer 16 of aluminum nitride, of silicon carbide, an alloy of aluminum and of gallium, and alloy of gallium and indium, or some other compound. The working layer 16 of gallium nitride can also be replaced by a multilayer structure constituting a stack of layers of the gallium nitride, aluminum nitride, gallium and indium nitride, etc. types, possibly having different kinds of doping, etc.

In yet other variants, the polycrystalline silicon carbide support 12 is replaced by monocrystalline silicon carbide (in particular when the support 12 can be recycled as mentioned below), sapphire, polycrystalline aluminum nitride, or polycrystalline gallium nitride.

After growing the working layer 16, the support 12 is removed, possibly after reinforcing the structure as a whole, where necessary for questions of strength, by means of some other support either by direct adhesion, or by forming said other support by depositing it on the working layer, etc.

The support 12 must then be capable not only of withstanding the conditions under which the working layer 16 is grown, but is advantaged by being suitable for removal. The technique selected for withdrawing the intermediate support 12 can determine the material selected for constituting it. If it is to be sacrificed by etching or by mechanical or chemical removal, then the etching and removal steps and also the intermediate support 12 itself must be as low cost as possible. Under such circumstances, the support 12 should be made of polycrystalline aluminum nitride.

Detaching

In the invention, stresses such as mechanical, thermal, electrostatic, laser irradiation, etc. are used to cause the assembly to split into two portions situated on either side of the adhesion interface.

Under such circumstances, the support 12 can be made of monocrystalline silicon carbide since it is not consumed and can be reused.

In another variant, all or some of the components on the working layer 16 are made either before or after removing the support 12.

In a second implementation of the method of the invention, as shown in Figure 2, a structure is made as in the first implementation of the method of the invention as described above, the structure comprising a working layer 16 on a seed layer 2 itself on a support 12 with bonding layers 10 and 11 interposed between the seed layer 2 and the support 12. Then, in accordance with the present implementation, a thick layer 4 is deposited on the free surface of the working layer 16 and the support 12 is removed, possibly together with the seed layer 2. The thick layer 4 then serves in particular to form a support for the working layer 16, after the support 12 has been removed.

Table 3 below summarizes examples of materials that can be used in the context of this second implementation of the method of the invention.

Table 3

Working layer 16	Seed layer 2	Bonding layers 10, 11	Support 12	Thick layer 4
GaN or AlN or AlGaN or GaInN or SiC or other	{111} Si or mono SiC or GaN or sapphire or $NdGaO_2$ or $LiGa_3$	SiO_2 or Si_3N_4	Poly SiC or poly AlN or sapphire or mono SiC or poly GaN	Diamond or poly SiC or GaN or AlN or boron nitride or metal (copper)

EXAMPLE 6

In this example, a seed layer 2 of monocrystalline {111} silicon is made on a polycrystalline silicon carbide support 12 with silicon oxide bonding layers 10 and 11 between them. Thereafter a working layer 16 of monocrystalline gallium nitride is deposited by MOCVD and a thick layer 4 of diamond is deposited on the free face of the monocrystalline gallium nitride of the working layer 16.

Thereafter the resulting structure is subjected to treatment suitable for detaching the assembly constituted by the working layer 16 from the assembly constituted by the support 12 and the seed layer 2. This treatment comprises using mechanical, thermal, electrostatic, etc. stresses to cause two portions to become separated on either side of the adhesion interface.

This example presents the advantage of making it possible to use a support 12 whose surface that is to receive the seed layer 2 is poorly finished, but once the working layer 16 of GaN has been formed by virtue of the

seed layer 2 of {111} silicon, it is possible to make a final support (the thick layer 4) for the working layer 16 that has properties adapted to using said working layer 16 (in this case, with diamond, it is the good thermal conductivity and electrical insulating properties that are desired, e.g. for microwave applications), and it is also possible to ensure a high quality interface between the thick layer 4 and the working layer 16, e.g. to obtain better heat conduction.

This example can comprise numerous variants.

Thus, the seed layer 2 of {111} silicon can be replaced by monocrystalline silicon carbide, sapphire, neodymium gallate, or lithium gallate; the bonding layers 10 and 11 of silicon oxide can be replaced by silicon nitride; the polycrystalline silicon carbide support 12 can be replaced by monocrystalline silicon carbide or by sapphire; and the thick layer 4 of diamond can be replaced by polycrystalline silicon carbide, by polycrystalline gallium nitride (e.g. deposited by HVPE), by boron nitride, or by a metal such as copper, etc. (e.g. deposited as a thick layer by electrolysis).

It should be observed that the thickness properties of the thick layer 4 can be of importance, for example when it is desired to make electrical contact with the rear face of the final substrate 14 or when it is essential to be able to evacuate the heat generated by components made on the working layer 16, or indeed when it is desired to improve extraction and control of light emitted by a diode or a laser made in the working layer 16. It will then be understood that the properties selected for the thick layer 4 provide a degree of freedom in substrate fabrication methods that is particularly advantageous when making substrates for optics, electronics, optoelectronics, etc. It is also possible to add a degree of freedom in substrate fabrication methods by providing preparation steps (known in themselves to the person skilled in the art) in order

to enable the thick layer 4 to be subsequently separated from the working layer 16.

Similarly, these variants can be transposed to situations in which a working layer 16 is made of aluminum nitride, of silicon carbide, an alloy of aluminum and gallium, or of other compounds, instead of making the working layer 16 out of gallium nitride as described above. The gallium nitride working layer 16 can also be a multilayer structure stacking layers of the gallium nitride, aluminum nitride, etc. type, possibly with doping of different kinds, etc.

In a third implementation of the method of the invention as shown in Figure 3, a structure is made in which the thick layer 4 is deposited after the working layer 16 and the seed layer 2 have been separated, contrary to that which is described above with reference to the second implementation of the invention. The thick layer 4 can then either be deposited on the same side as the free face of the working layer 16 or else it can be deposited on the same side as the seed layer 2, either on said seed layer 2 or on the corresponding face of the working layer 16, if the seed layer 2 is removed either together with the support 12 or after the support 12 has been removed.

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 4, and they correspond to the materials of Table 3.

Table 4

Working layer 16	Seed layer 2	Bonding layers 10, 11	Support 12	Thick layer 4
GaN or AlN or AlGaN or GaInN or SiC	Mono SiC or {111} Si or sapphire or GaN or $NdGaO_2$ or $LiGaO_3$	SiO_2 or Si_3N_4	Mono SiC or poly SiC or poly AlN or sapphire or poly GaN	AlN or GaN or poly SiC or diamond or boron nitride or metal
GaN or AlN or AlGaN or GaInN or SiC	Mono SiC or {111} Si or sapphire + etching GaN or $NdGaO_2$ or $LiGaO_3$	SiO_2 or Si_3N_4	Mono SiC or poly SiC or poly AlN or sapphire or poly GaN	AlN or GaN or poly SiC or diamond or boron nitride or metal
+ etching a portion of the GaN or the AlN or the AlGaN or the GaInN or the SiC	Mono SiC or {111} Si or sapphire + etching GaN or $NdGaO_2$ or $LiGaO_3$	SiO_2 or Si_3N_4	Mono SiC or poly SiC or poly AlN or sapphire or poly GaN	Poly SiC or diamond or boron nitride or metal

EXAMPLE 7

In this example (first row of Table 4), a structure is made comprising a monocrystalline silicon carbide seed layer 2 on a monocrystalline silicon carbide support 12 with silicon oxide bonding layers 10 and 11 between them, in the same manner as that described above for Example 1. Thereafter, a working layer 16 of monocrystalline gallium nitride is made on the free surface of the silicon

carbide seed layer 2 by MOCVD. The structure obtained in this way is then subjected to treatment suitable for separating the structure constituted by the seed layer 2 and the working layer 16 from the support 12. This provides firstly a structure constituted by a gallium nitride working layer 16 covered in a seed layer 2 of monocrystalline silicon carbide, and a support 12 that is ready for recycling. A thick layer 4 of polycrystalline silicon carbide is then deposited by CVD on the seed layer 2.

The monocrystalline silicon carbide support 12 is relatively expensive, but in the present example it is recycled when implementing the method of the invention on a subsequent occasion.

EXAMPLE 8

In another example (second row of Table 4) of this third implementation of the method of the invention, the same structure is made as in Example 7, but the seed layer 2 of monocrystalline silicon carbide is withdrawn, e.g. by plasma etching, prior to forming the thick layer 4 of polycrystalline silicon carbide.

EXAMPLE 9

In yet another example of this third implementation of the method of the invention (third row of Table 4), a structure is made as in Example 8, except that not only is the seed layer 2 of monocrystalline silicon carbide removed, but so also is a portion of the working layer 16 of gallium nitride so as to conserve a working layer 16 that presents as few defects as possible.

It can be observed that the seed layer 2 of monocrystalline silicon carbide or the working 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, these steps seeking to provide some or all of the electronic

components, or comprising making uniform deposits of additional films, either epitaxially or otherwise.

It should also be observed that the polarity of the seed layer 2 of monocrystalline silicon carbide (Si face or C face) and the polarity of the working layer 16 of gallium nitride can be determined by the polarity selected for the initial source substrate 6. The method of the invention optionally includes at least one double transfer enabling polarity to be changed twice over.

Similarly, these examples can be transposed to situations in which, in accordance with the invention, a working layer 16 is made of aluminum nitride, of silicon carbide, of aluminum and gallium alloy, of indium and gallium alloy, or of some other compound, instead of making the working layer 16 out of gallium nitride as described above. The gallium nitride working layer 16 can also be a multilayer structure comprising a stack of layers of the gallium nitride, aluminum nitride, etc. types, optionally with different kinds of doping, etc.

The seed layer 2 can be made of {111} silicon or of sapphire or of neodymium gallate, or of indium gallate, etc. instead of being made of monocrystalline silicon carbide.

The support 12 can be made of polycrystalline silicon carbide or of polycrystalline silicon nitride or of polycrystalline aluminum nitride or of sapphire or of polycrystalline gallium nitride, instead of being made of monocrystalline silicon carbide. The thick layer 4 can be made of polycrystalline aluminum nitride, of diamond, or of boron nitride, instead of being made of polycrystalline silicon carbide.

In the fourth implementation of the method of the invention, a structure is made as in the above examples, except that no intermediate layers 10 and 11 are made. For example, a seed layer 2 is taken from a source substrate 6 of {111} silicon, and is assembled with a polycrystalline silicon carbide support 12 by direct

adhesion (e.g. as described in the preceding implementations). Thereafter, one of the techniques mentioned above is used to deposit a working layer 16 of gallium nitride on the seed layer 2.

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

For example, the operations described in different examples of the implementations of the method of the invention can be combined with one another.

As shown in Figure 4, one variant consists in performing batch treatment on the seed layers 2 prior to depositing the working layer 16. Under such circumstances, the seed layers 2 are fixed on a common support 12 of large size.

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

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

Advantageously, a stiffening substrate is bonded to the working layer 16 of each of the various assemblies prior to the operation seeking to detach the working layer assembly 16 on the seed layers 2 from the support 12.

Each common support 12 is recycled.

In another variant of the method of the invention, the parameters governing deposition of the thick layer 4 are optimized so as to make a thick layer 4 that is monocrystalline.

Even if the monocrystalline thick layer 4 is not of best quality, its quality can nevertheless be sufficient

in numerous applications, whenever very high crystal quality is required only for the working layer 16.

The method of the invention is particularly advantageous when single crystals cannot be grown (as is the case of gallium nitride) or when they are difficult to grow (as is the case for silicon carbide).

In other variants, the description above can be transposed to growing a working layer out of other semiconductor materials, such as indium phosphide, gallium arsenide, germanium, silicon-germanium, etc., or indeed other materials such as lithium niobate.

In yet other variants, bonding layers 10 or 11 are not used, or only one such layer is used (either on the support 12 or on the seed layer 2).

In yet other variants, an intermediate layer is made, e.g. an insulating layer, between the working layer 16 and/or the seed layer 2 (if it is conserved) and the support 12 or the thick layer 4 so as to form a substrate comprising a semiconductor on insulation. By way of example the intermediate layer can be made of diamond, of fine oxide (500 Å thick), etc.

CLAIMS

1/ A method of fabricating substrates, in particular for optics, electronics, or optoelectronics, the method being characterized by the fact that it comprises the following steps:

· transferring a seed layer onto a support by molecular adhesion in an adhesion interface;

· growing a working layer epitaxially on the seed layer; and

· applying stresses to cause the assembly constituted by the seed layer and the working layer to become detached from the support at the adhesion interface.

2/ A method according to claim 1, characterized in that the stresses applied to perform separation are taken from the group comprising: mechanical stresses, thermal stresses, electrostatic stresses, and laser irradiation stresses.

3/ A method according to claim 1 or claim 2, characterized by the fact that the support is constituted by a material whose coefficient of thermal expansion is 0.7 to 3 times the coefficient of the working layer , and the seed layer is suitable for accommodating the thermal expansion of the support and of the working layer.

4/ A method according to claim 3, characterized by the fact that the seed layer possesses crystal lattice parameters such that the working layer is grown epitaxially on the seed layer with dislocations in the working layer being at a concentration of less than $10^7/cm^2$.

5/ A method according to any preceding claim, characterized by the fact that at least one bonding layer

is interposed between the seed layer and the support , the adhesion interface involving the or each bonding layer.

6/ A method according to any preceding claim, characterized by the fact that the working layer is made of gallium nitride.

7/ A method according to any preceding claim, characterized by the fact that the seed layer comprises a material taken from the list comprising: sapphire, silicon carbide, zinc oxide, {111} silicon, gallium nitride, neodymium gallate, and lithium gallate.

8/ A method according to any preceding claim, characterized by the fact that the support comprises a material taken from the list comprising: amorphous materials, polycrystalline materials, and sintered materials.

9/ A method according to claim 7, characterized by the fact that the support comprises a material taken from the list comprising: polycrystalline silicon carbide, monocrystalline silicon carbide, polycrystalline aluminum nitride, and sapphire.

10/ A method according to any preceding claim, characterized by the fact that the seed layer has the same chemical composition as the support .

11/ A method according to any preceding claim, characterized by the fact that the seed layer is taken from a source substrate by separating the seed layer from the source substrate via a pre-weakened zone .

12/ A method according to claim 10, characterized by the fact that the pre-weakened zone is made by implanting atomic species in the source substrate at a depth corresponding to the thickness of the source substrate .

13/ A method according to claim 10 or claim 11, characterized by the fact that the seed layer is separated from the source substrate by an operation taken from the list comprising: heat treatment, applying mechanical stresses, and chemical etching, or a combination of at least two of these operations.

14/ A method according to any preceding claim, characterized by the fact that the working layer is deposited with a thickness of less than 10 microns, and preferably less than 5 microns.

A B S T R A C T

The invention provides a method of fabricating substrates, in particular for optics, electronics, or optoelectronics. The method comprises the following steps:

· transferring a seed layer (2) onto a support (12) by molecular adhesion in an adhesion interface;

· growing a working layer (16) epitaxially on the seed layer; and

· applying stresses to cause the assembly constituted by the seed layer (2) and the working layer (16) to become detached from the support (12) at the adhesion interface.