CREATION OF AN ELECTRICALLY CONDUCTING BONDING BETWEEN TWO SEMI-CONDUCTOR ELEMENTS

Technical field

This invention relates to a method that permits the creation of an electrically conducting bonding between two semi-conductor elements.

State of the prior art

The transfer of a thin film of semi-conductor material onto a support is often used in the field of micro-electronics. This is the case particularly for devices produced on GaAs for which it is preferable to lay a substrate made up of a thin film of GaAs on a silicon support. This solution offers several advantages. It enables one to reduce the costs since GaAs is an expensive material in relation to silicon. It enables one to simplify handling since GaAs is fragile and therefore must be handled delicately. It also enables one to reduce the weight of the components, which is an important parameter for space applications, since silicon is lighter than GaAs.

Such a transfer is made traditionally by bonding using an oxide, this type of bonding being easy to control. However, bonding using an oxide has the particular feature that the thin film is electrically insulated from its support. Hence, for certain applications it is necessary to establish vertical electrical conduction through the substrate. This is the case particularly for diodes produced on a film of SiC formed on a silicon support and for solar cells produced by deposition of GaAs on silicon.

Furthermore, certain types of transistors (for example, transistors with a permeable base or a metal base) necessitate having a metal layer buried under the layer of semi-conductor from which they are produced. This type of layer is difficult to create and conductive bonding is the most simple way of producing this type of structure.

Several solutions have been proposed for creating conducting bonding of two plates of silicon. One may mention the article "Buried Cobalt Silicide Layers in Silicon Created by Wafer Bonding" by K. LJUNGBERG et al., that appeared in J. Electrochem. Soc., Vol. 141, No. 10, October 1994, pages 2829-2833 and the article "Low Temperature Silicon Wafer to Wafer Bonding with Nickel Silicide" by Zhi Xiong Xiao et al., that appeared in J. Electrochem. Soc., Vol. 145, No. 4, April 1998, pages 1360-1362. All these solutions consist of forming a silicide from a metal deposited on the faces of the plates to be bonded, by reaction of the metal and the semi-conductor material. These solutions have two disadvantages. On the one hand, the formation of the silicide consumes a part of the semi-conductor film which may be a disadvantage in the case of very thin films. On the other hand, there is diffusion of the metal into the semi-conductor, which has the consequence of degrading its properties. This is particularly the case if nickel is used. Furthermore, the compounds formed are not stable at high temperature which restricts the possibilities for heat treatment after creation of the bonding. These two things can be very important, if one wishes, after bonding to carry out an epitaxy which can involve the

use of high temperatures (of the order of 1600°C in the case of SiC).

Description of the invention

So as to remedy the disadvantages mentioned above, according to this invention, it is proposed to use a bonding that uses one or more layers that do not react with at least one of the two semi-conductor materials to be electrically connected.

Therefore the subject of the invention is a method for creating an electrically conducting bonding between a face of a first semi-conductor element and a face of a second semi-conductor element by means of heat treatment, consisting of :

- depositing at least one layer of material on said face of the first semi-conductor element and at least one layer of material on said face of the second semi-conductor element, these deposited layers combining during said heat treatment to form a layer that provides an electrically conducting bonding between the two faces,

- applying said faces one against the other, with interposing of said layers of deposited material between them,

- carrying out said heat treatment, characterized in that the layer of material deposited onto said face of the first semi-conductor element and the layer of material deposited onto said face of the second semi-conductor element are chosen in order to react in the solid phase during the heat treatment and to form a temperature stable mixture with respect to the first and the second semi-conductor element, the heat treatment not inducing any reaction product between the

deposited materials and at least one of the semi-conductor elements.

According to one particular embodiment, the material of the layer deposited on the face of the first semi-conductor element is distinct from the material of the layer deposited on the face of the second semi-conductor element, the heat treatment forming a mixture that does not induce any reaction product with the first and the second semi-conductor.

According to another particular embodiment, one of the layers of material is deposited with an excess thickness such that a part of this layer, in contact with the other layer of material combines with the other deposited layer of material in order to form said stable mixture, the other part of the layer deposited with an excess thickness, in contact with the semi-conductor element on which it is deposited, reacting during the heat treatment with this semi-conductor element in order to form a film with ohmic contact.

A layer of oxide may be provided between the deposited layers of material, the oxide being chosen in order to react with at least one material of said deposited layers, the thicknesses of the oxide layer and the layer of material with which the oxide reacts being such that the oxide formed is in the form of isolated precipitates which do not substantially harm the electrically conducting bonding. This layer of oxide may be deposited on one of the layers of material or on both of them, for example, by a method chosen from among vacuum deposition and sol-gel type deposition.

In order to improve the bonding, the first and second semi-conductor elements can be pressed one against the other during the heat treatment.

The electrically conducting bonding may result from a mixture of identical materials. By way of an example, the first semi-conductor element is SiC and the second semi-conductor element is SiC, the intermediate layers comprising a layer of tungsten and a layer of silicon on said face of the first semi-conductor element and a layer of tungsten and a layer of silicon on said face of the second semi-conductor element, the mixture formed after the heat treatment comprising WSi_2.

If one of the semi-conductor elements is a thin film, the method may comprise a preliminary step consisting of defining this thin film as a superficial layer of a substrate, intended to be separated from the rest of the substrate. According to a first embodiment example, during the preliminary step, the substrate is formed by stacking a support, a sacrificial layer and the thin film, the separation of the thin film from the rest of the substrate being obtained, after creation of the bonding, by dissolution of the sacrificial layer. According to a second embodiment example, during the preliminary step, the thin film is bounded in a substrate by a layer of micro-cavities obtained by ionic implantation, the separation of the thin film from the rest of the substrate being consecutive to the bonding heat treatment or to a specific heat treatment or to the application of mechanical forces or to the combination of a heat treatment and the application of mechanical forces.

Brief description of the drawings

The invention will be better understood and other advantages and particular features will become apparent on reading the description that follows, given by way of a non-limitative example and accompanied by the appended drawings among which :

- Figures 1A to 1D illustrate a first example of the creation of an electrically conducting bonding between two semi-conductor elements, according to the method of the invention,

- Figures 2A to 2E illustrate a second example of the creation of an electrically conducting bonding between two semi-conductor elements, according to the method of the invention,

- Figures 3A to 3D illustrate a third example of the creation of an electrically conducting bonding between two semi-conductor elements, according to the method of the invention.

Detailed description of embodiments of the invention

The invention proposes the creation of a bonding using layers which do not react with one or the other of the semi-conductor elements to be electrically connected.

According to the invention, the materials interposed between the two elements to be bonded react during the heat treatment to form a mixture stable with respect to these elements at high temperatures and notably temperatures greater than that of the heat treatment. This stability at high temperature is particularly important when the elements are made of SiC and one of them must be subjected to epitaxy.

The method according to the invention does not require the use of a diffusion barrier although a diffusion barrier may be used.

Preferably, the interposed materials are :

- W (or a compound based on W)/Si
- W (or a compound based on W)/Si/W (or a compound based on W).

The thicknesses of the interposed layers are generally dimensioned so that all of the materials in these layers interact to form a new stable material. However, in certain cases, it may be advantageous to use at least one layer of material having an excess thickness. This excess thickness of material then reacts during the high temperature heat treatment with the element with which it is in contact in order to form a film with ohmic contact.

By way of example, for elements to be bonded made of SiC and interposed layers made of W and Si, in order for all of the interposed layers to react, the ratio of the total thickness of the Si layer or layers to the total thickness of the W layer or layers must be equal to or close to 2.5 in order to obtain a homogeneous layer of WSi_2. In order to have an excess thickness capable of reacting, it must be slightly below 2.5. This enables one to have a thin film based on WSi and WC which is also stable at high temperature.

According to a kinetic approach, layers are used which are only thermodynamically stable with one or the other of the semi-conductor materials at the temperatures used during production of the devices and during their use, after the heat treatment for bonding the two semi-conductor elements. For example, in the case of the transfer of silicon carbide onto silicon

carbide, the following stacks can be used : SiC element/W layer/Si layer-Si layer/W layer/SiC, the silicon being amorphous or crystalline. During the heat treatment, the tungsten reacts with the silicon to form WSi_2. For a structure SiC/W (thickness 0.1 μm)/Si (thickness 0.25 μm)-Si(thickness 0.25 μm)/W (thickness 0.1 μm)/SiC, SiC/WSi_2/SiC is obtained. Reaction occurs from 650°C, implying reaction of the silicon with the tungsten, without the thin film of SiC being consumed and the system is stable at more than 1600°C.

Figures 1A to 1D are transverse views which illustrate a first embodiment example of the method according to the invention for which the bonding is carried out in accordance with a kinetic approach. Figure 1A shows a SiC plate 10 covered successively with a layer 11 of tungsten and a layer 15 of silicon. Figure 1B shows a SiC plate 12 covered successively with a layer 13 of tungsten and a layer 16 of silicon. Figure 1C shows the joining of the structures shown in Figures 1A and 1B, theses structures being brought into contact through their layers 15 and 16. After heat treatment from 650°C, the assembly shown in Figure 1D is obtained. The SiC plate 10 is connected by an electrically conducting bonding to the SiC plate 12 thanks to the intermediate layer 14 formed between the two plates and comprising WSi_2.

Such an electrically conducting bonding can be used to bond a thin semi-conductor film onto a semi-conductor support. So as to obtain this thin film, the thickness of one of the two bonded plates may be reduced. This has two major disadvantages. On the one hand, it is difficult to obtain a thin film homogeneous

throughout its thickness and, on the other hand, there is a loss from the rest of the semi-conductor plate supplying this film. This invention also enables one to remedy these disadvantages. A first solution makes use of a sacrificial layer. A second solution employs a cleavage method after ionic implantation.

Figures 2A to 2E are transverse views which illustrate the creation of an electrically conducting bonding, in accordance with a kinetic approach, between a semi-conductive SiC plate and a thin SiC film obtained by dissolution of a sacrificial layer. Figure 2A shows a silicon plate 30 covered with a layer 31 of silicon oxide or silicon nitride which will be used as a sacrificial layer. The sacrificial layer 31 is covered successively with a SiC layer 32, which will provide the thin film, a layer 33 of tungsten and a layer 37 of silicon. Figure 2B shows a SiC plate 34 covered with a layer 35 of tungsten and a layer 38 of silicon. Figure 2C shows the joining of the structures shown in Figures 2A and 2B, these structures being brought into contact through their layers 37 and 38. After heat treatment from 650°C, the assembly shown in Figure 2D is obtained. The SiC layer 32 is connected through an electrically conducting bonding to the SiC plate 34 thanks to the intermediate layer 36 constituted by WSi_2. The sacrificial layer is then dissolved by a technique known to a man skilled in the art. On obtains, on the one hand, the structure shown in Figure 2E, that is to say a thin film of SiC bonded through an electrical connection to a SiC support, and on the other hand, a reusable silicon plate.

Figures 3A to 3D are transverse views which illustrate the creation of an electrically conducting

bonding, in accordance with a kinetic approach, between a semi-conductive SiC plate and a thin SiC film obtained by cleavage after ionic implantation. Figure 3A shows a SiC plate 50 within which a layer 51 of micro-cavities has been generated by ionic implantation, through one of the faces of the plate 50, in accordance with the technique disclosed by the document FR-A-2 681 472. A layer 52 of tungsten and a layer 57 of silicon have been successively deposited on the implanted face of the plate 50. Figure 3B shows a plate 53 of SiC covered with a layer 54 of tungsten and a layer 58 of silicon. Figure 3C shows the joining of the structures shown in Figures 3A and 3B, these structures being brought into contact through their layers 57 and 58. After heat treatment, the assembly shown in Figure 3D is obtained. The heat treatment causes cleavage of the plate 50 along the layer of micro-cavities. A thin film 55 of SiC remains, which is connected by an electrically conducting bonding to the SiC plate 53 thanks to the intermediate layer 56 comprising WSi_2. The remainder of the plate 50 can then be reused.

In an advantageous way, so as to improve the bonding, pressure can be applied between the assembled structures. One may also, conjointly or not, use a thin layer of oxide on the surface of at least one of the structures in order to reduce the pressure necessary for the bonding, or indeed do without it. This layer of oxide must be sufficiently fine (a few Angströms) and capable of interacting with at least one of the bonding materials to form, at the end of the process, precipitates which do not hinder the electrical conduction. During the heat treatment, the thin layer

of oxide reacts with the metal which is offered to it, if the metal is sufficiently electropositive, to form metal oxides which are in the form of isolated precipitates. In particular, this is the case with titanium which reacts with the oxide SiO_2 to form TiO_2 and releasing silicon. Hence a stack SiC/SiO_2 (of thickness 0.01 μm)-SiO_2 (of thickness 0.01 μm)/Ti (of thickness 0.1 μm)/Si provides the structure $SiC/(TiSi_2 + TiO_x)/Si$. The reaction occurs at 1000°C, implying reaction of the silicon with the titanium and reduction of the SiO_2 by the titanium, without the thin film of SiC being consumed. The SiO_2 must be thin so that the TiO_2 does not form a continuous layer. The system is stable up to 1330°C (limited by the formation of a eutectic between $TiSi_2$ and Si at this temperature).

The description above can be applied to the bonding of other elements. Hence, for example, one may bond a layer of GaN epitaxiated on a substrate of sapphire or SiC with a SiC substrate by interposing at least two layers of materials, respectively W and Si.

CLAIMS

1. Method of creating an electrically conducting bonding between a face of a first semi-conductor element (10, 32, 55) and a face of a second semi-conductor element (12, 34, 53) by means of heat treatment, consisting of:

- depositing at least one layer of material on said face of the first semi-conductor element and at least one layer of material on said face of the second semi-conductor element, these deposited layers combining during said heat treatment to form a layer that provides an electrically conducting bonding between the two faces,

- applying said faces one against the other, interposing said layers of deposited material,

- carrying out said heat treatment, characterized in that the layer of material (11, 15, 33, 37, 52, 57) deposited on said face of the first semi-conductor element and the layer of material (13, 16, 35, 38, 54, 58) deposited on said face of the second semi-conductor element are chosen in order to react in solid phase during the heat treatment and to form a mixture that is stable for a temperature higher than the heat treatment temperature for the first (10, 32, 55) and for the second (12, 34, 53) semi-conductor element respectively, the heat treatment not inducing any reaction product between the deposited materials and at least one of the semi-conductor elements.

2. Method according to Claim 1, characterized in that during the preliminary step, the thin film is bounded in a substrate (50) by a layer of micro-cavities (51) obtained by ionic implantation, the

second semi-conductor element, the heat treatment forming a mixture that does not induce any reaction product with the first and the second semi-conductor element.

3. Method according to one of Claims 1 or 2, characterized in that one of the layers of material is deposited with an excess thickness such that a part of this layer, in contact with the other layer of material combines with the other deposited layer of material in order to form said stable mixture, the other part of the layer deposited with an excess thickness, in contact with the semi-conductor element on which it is deposited, reacting during the heat treatment with this semi-conductor element in order to form a film with ohmic contact.

4. Method according to Claim 1, characterized in that a layer of oxide is provided between said deposited layers of material, the oxide being chosen in order to react with at least one material of said deposited layers, the thicknesses of the oxide layer and the layer of material with which the oxide reacts being such that the oxide formed is in the form of isolated precipitates which do not substantially harm the electrically conducting bonding.

5. Method according to Claim 4, characterized in that said layer of oxide is deposited on one of the deposited layers of material or on both of them.

6. Method according to Claim 1, characterized in that the first and second semi-conductor elements are

pressed one against the other during the heat treatment.

7. Method according to Claim 1, characterized in that the first semi-conductor element is SiC and the second semi-conductor element is SiC, the interposed layers comprising a layer of tungsten and a layer of silicon on said face of the first semi-conductor element and a layer of tungsten and a layer of silicon on said face of the second semi-conductor element, the mixture formed after the heat treatment comprising WSi_2.

8. Method according to any one of the preceding Claims, characterized in that, one of the semi-conductor elements being a thin film (32, 55), the method comprises a preliminary step consisting of defining this thin film as a superficial layer of a substrate, intended to be separated from the rest of the substrate.

9. Method according to Claim 8, characterized in that during the preliminary step, the substrate is formed by stacking a support (30), a sacrificial layer (31) and the thin film (32), the separation of the thin film from the rest of the substrate being obtained after creation of the bonding, by dissolution of the sacrificial layer (31).

10. Method according to Claim 8, characterized in that during the preliminary step, the thin film is bounded in a substrate (50) by a layer of micro-cavities (51) obtained by ionic implantation, the

separation of the thin film from the rest of the substrate being consecutive to the bonding heat treatment or to a specific heat treatment or to the application of mechanical forces or to the combination of a heat treatment and the application of mechanical forces.