SUBSTRATES FOR STRESSED SYSTEMS

Field of the invention and prior art

The invention relates to the field of substrates used in particular in microelectronics or optoelectronics, such as silicon or silicon carbide substrates.

In this field, substrates often have to be assembled together. However, such substrates do not necessarily have the same properties, in particular thermal properties. Problems thus arise as regards stresses, both tensile and compressive, when the assembly is subjected to phases in which the temperature rises and/or falls, sometimes over amplitudes of the order of 1000°C.

One and/or the other of said substrates may be damaged (for example by the appearance of cracks) under the effect of the stresses, or it may simply be destroyed.

Examples of such assemblies are GaAs (gallium arsenide)-Si, sapphire-silicon, germanium-silicon (Si-Ge), silicon-quartz or gallium nitride (GaN)-silicon.

One of the substrates may itself be an assembly of layers, or it may be no more than a layer or a film.

Thus, a problem arises when assembling together two substrates, or a substrate and a layer, or a substrate and a set of layers with different thermal expansion coefficients, with the set possibly being subjected to temperature excursions over quite a wide range, of the order of 1000°C or more.

Description of the invention

Embodiments of the invention provide a structure assembled from first and second substrates respectively having first and second assembly faces, motifs being formed or produced or etched into the second substrate from its assembly face and/or from the face of said second substrate opposite to the assembly face.

In accordance with a first aspect of the invention, there is provided a structure assembled from a film and a substrate, said film being produced from a second substrate by thinning, said film and said first substrate respectively having a first thermal expansion coefficient and a second thermal expansion coefficient which differs from the first, and respectively having first and second assembly faces, wherein motifs are formed in the substrate into the face opposite to that on which the film is bonded, said motifs being elastic or being flexible in a plane parallel to the first and second assembly faces so as to form a mechanical system for absorbing thermoelastic stresses generated at the assembly interface.

The motifs produced in one and/or the other of said faces may provide the substrate in which they are produced with elasticity in a plane parallel to the assembly faces.

This type of structure thus employs mechanical means or a mechanical system (obtained, for example, by etching or by producing motifs) that can absorb thermoelastic stresses generated at the assembly interface.

The two substrates can then have thermal expansion coefficients that differ by at least 10%, for example, at ambient temperature.

As an example, one of the substrates can be formed from silicon, quartz, sapphire, silicon carbide or glass, and the other can be formed from gallium arsenide, sapphire, silicon-germanium (SiGe), indium phosphide, aluminum nitride or silicon carbide.

The first substrate can be in the form of a film comprised of one or more thin layers, each with a thickness in the range 0.1 micrometers (μm) to 2 μm, for example. In particular, the first substrate can be a film or a thin layer in order to form with the second substrate an assembly which can be used as a device for forming layers by heteroepitaxy. Thus, the motifs formed in the second substrate may allow to absorb thermoelastic or mechanic stresses which can be generated during the heteroepitaxial depositing.

The structure can be of the SOI type with a layer of silicon, a layer of oxide or insulator, and a substrate.

Example embodiments of the invention also provide a method of assembling first and second substrates respectively having first and second assembly faces, motifs having been produced in the second substrate. Said motifs are elastic or are flexible or provide the substrate in which they are

produced with elasticity, in a plane parallel to the assembly faces of the two substrates.

The set of the two assembled-together substrates can undergo a step in which the temperature is raised and then dropped; the etched motifs can absorb mechanical stresses generated during the temperature rise or fall.

In accordance with a second aspect of the invention, there is provided a method for producing a film formed from a first material on a substrate formed from a second material, the method comprising:

- assembling together, first and second substrates respectively having a first thermal expansion coefficient and a second thermal expansion coefficient, which differs from the first, and respectively having first and second assembly faces, in which motifs have been formed into the face of the second substrate which is opposite to that bonded with the first substrate, said motifs being elastic or being flexible in a plane parallel to the first and second assembly faces so as to form a mechanical system for absorbing thermoelastic stresses generated at the assembly interface,

- separating a portion of one of the substrates or thinning one of the substrates, to leave a film on the other substrate.

Brief description of the Figures

- Figures 1A, 1B, 1C and 2 show implementations of the invention;
- Figures 3A and 3B, also 4A and 4B, show steps in two variations of a substrate fracture technique.

Detailed description of implementations of the invention

One aspect of the invention is described below with reference to Figure 1A.

This concerns assembling together two substrates 40, 42 which can have different thermal expansion coefficients c_0 and c_2, for example a quartz substrate (expansion coefficient $5 \times 10^{-7}\ K^{-1}$) or AsGa (expansion coefficient $6 \times 10^{-6}\ K^{-1}$) and a silicon substrate (expansion coefficient $2.5 \times 10^{-6}\ K^{-1}$).

Germanium (expansion coefficient $6 \times 10^{-6}\ K^{-1}$), alumina (Al_2O_3, expansion coefficient $7 \times 10^{-6}\ K^{-1}$) and silicon carbide SiC (expansion coefficient $4.5 \times 10^{-6}\ K^{-1}$) are examples of other possible materials.

The difference in the thermal expansion coefficient between substrates 40 and 42 (in fact, the relative difference $|c_0 - c_2|/c_0$ or $|c_0 - c_2|/c_2$) is preferably determined at ambient temperature, at about 20°C or 25°C: it is at least 10%, or at least 20% to 30% at ambient temperature.

Each substrate 40, 42 can be of the order of several hundred µm thick, for example in the range 100 µm to 1 millimeter (mm) thick.

However, as described below, one substrate can be in the form of one or more thin layers, each with a thickness in the range 0.1 µm to 2 µm, for example. Such an assembly can be used as a device for forming layers by heteroepitaxy.

In one of the substrates (in this case substrate 42), an elastic accommodation layer 45 is formed and has a certain amount of elasticity in at least a plane xy parallel to its face 43 for assembly with the substrate 40. Said layer can be obtained by etching, for example by ion etching, at the surface or from the surface 43. Thus, studs or trenches or any other geometrical motif, preferably periodical, can be formed. Said motifs are elastic or are flexible in a plane parallel to the plane of the interface of the two substrates 40, 42. The resulting elasticity can be calculated by applying conventional beam theory.

Thus, a mechanical system of absorbing elements or mechanical stress absorbing means is produced.

In a variation, shown in Figure 1B, an elastic accommodation layer 49 can be formed in a rear face 47 of the substrate 42, which can avoid any problems with adhesion between the substrate 40 and the substrate 42 which may occur in the configuration of Figure 1A. This variation can also absorb stresses.

In another variation, shown in Figure 1C, cuts 51 resembling saw cuts are produced in the substrate 42 from one side and/or the other side of the substrate, defining slices of substrate. Here again, a stress absorbing effect is obtained.

The etched or hollowed motifs are preferably repeated in a two-dimensional periodic pattern or in one dimension, as shown in Figures 1A-1C.

As an example, trenches with a depth p of 10 µm, a width ℓ of 1 µm and spaced apart by a distance e of 1 µm are hollowed into the substrate 42 to generate such a mechanical absorption system.

The two substrates 40, 42 are assembled with face 43 against face 41.

In the case of Figure 1A, if the assembly is obtained by molecular bonding of the substrate or the layer 40 to the substrate 42, bonding to a substrate with trenches may modify the bonding step, in particular as the surface area brought into contact may be substantially reduced (by about 50%, for example).

Preferably again, in the case of highly etched surfaces (thus with a small contact surface area or a very reduced contact surface area), the distribution of the trenches or studs can be optimized to permit spontaneous bonding. To this end, the geometrical parameters of the motifs, for example the width and/or periodicity, can be adjusted.

In order to obtain an etched substrate and to be able to keep the bonding surface planar, it is possible to partially or completely obturate the surface of the substrate prior to bonding. The stress absorbing effect would be retained even if the entire depth of the trenches or motifs were to be obturated.

In one example, if the surface is silicon, a step for smoothing the surface of substrate 42 can be carried out in a stream of hydrogen to partially or completely close the etching pits by migration of silicon atoms, as shown in Figure 2, in which reference number 48 indicates filling the trench with silicon over a certain depth h.

In a further example, a non conforming deposit (of an oxide, for example) is made which obturates the surface of the trenches. Said deposit can be produced by a non-optimized filling method of the Shallow Trench Isolation or STI type.

Such a method has been described, for example in "A highly Manufacturable Corner Rounding Solution for 0.18 µm Shallow Trench Isolation", C.P. Chang et al, IEDM 97-661.

Once assembly has been carried out, an element is provided which can absorb stresses by movement and/or deformation of the beams or studs or walls of the trenches or trenches defined by the cuts under the effect of the thermoelastic stress.

When assembling the two substrates 40, 42 or during any subsequent treatment of the two assembled substrates, temperature rise phases are carried out. Any variation in the quality of one of the two surfaces or one of the two substrates with respect to the other surface or the other substrate, which variation is due to the difference in thermal expansion coefficients, is then at least partially compensated for by a movement of the studs or motifs or trenches produced in the etched substrate 42.

Any rise or fall in temperature will cause the two surfaces 40, 42 to expand differently and cause a movement of the motifs or trenches in a plane xy parallel to that of the substrates.

This is particularly the case when the two surfaces are assembled with a view to producing a fracture in one of the substrates. That type of method is known as the "Smart-Cut" (or substrate fracture) method.

In view of this, the present invention also provides a method of assembling a substrate and a film each having different thermal expansion coefficient.

An example of such a method will now be described with reference to Figures 3A and 3B.

In a first step (Figure 3A), ion or atom implantation is carried out in a substrate 80 to form a thin layer 87 which extends substantially parallel to the surface 81 or the substrate 80. In fact, a layer or plane or zone of weakness or fracture is formed, which defines within the volume of the substrate 80a lower region 85 intended to constitute a thin film, and an upper region 84 constituting the bulk of the substrate 80. Said implantation is generally hydrogen implantation, but other species can also be used, as can hydrogen/helium co-implantation.

The two substrates 80 and 82 that are prepared are then assembled, face 83 against face 81, using a wafer bonding technique (assembling wafers by any technique that is known in the microelectronics art) or by adhesive contact (for example molecular bonding) or by bonding. Reference in this regard should be made to the work by Q.Y. Tong and U. Gösele, "Semiconductor Wafer Bonding", (Science and Technology), Wiley Interscience Publications.

A portion 84 of the substrate 80 is then removed by thermal or mechanical treatment to cause fracture along the plane of weakness 87. One example of this technique has been described in the article by A.J. Auberton-Hervé et al entitled "Why can Smart Cut Change the Future of Micro-electronics?" published in the International Journal of High Speed Electronics and Systems, Vol 10, n° 1, 2000, p 131-146.

A plane of weakness can be obtained by methods other than ion implantation. It is also possible to produce a layer of porous silicon as described by K. Sataguchi et al, in "ELTRAN® by Splitting Porous Si Layers", Proceedings of the 9th International Symposium on Silicon-on-Insulator Tech. and Device", 99-3, the Electrochemical Society, Seattle, p 117-121 (1999).

Other techniques can thin the substrates without employing ion implantation and without creating a plane of weakness: they are polishing or etching techniques.

The structure obtained is that of Figure 3B.

To strengthen the bonding or assembly interface between the substrate 82 (or its face 83) and the thin film 85 (or the contact face 81) it may be desirable to raise the temperature to about 1000°C.

During the different temperature rise stages, the structure of the motifs etched into the substrate 82, in particular their flexibility or elasticity, can compensate for or absorb stresses and differences in variations due to any differences between the thermal expansion coefficients of the two substrates 80, 82.

This is also applicable to a film 85 constituted by a set of superimposed films. In other words, this aspect of the invention concerns not only a substrate-substrate or monolayer-on-substrate system such as that described above, but any multilayer system involving depositing layers on a substrate.

The structure shown in figure 3B may be used advantageously as a substrate for forming layers by heteroepitaxy. Indeed, since motifs or trenches are etched in the substrate 82, the thermoelastic stresses that can

be generated when forming a heteroepitaxial layer on the thin film 85 are absorbed. Thanks to the elasticity or flexibility provided to the substrate 82 by the motifs, the defects occurring during growth or on during cool down from the difference in thermal expansion coefficient of the substrate and the heteroepitaxial layer can be minimized in comparison with a substrate not having such motifs

In view of this, the thin film 85 can serve as a seed layer for growing a heteroepitaxial layer for a larger range of thermal expansion coefficient. The assembled structure, namely substrate 82 with the thin film 85, can serve for growing heteroepitaxial layers such as GaN, AlN, InN or SiC layers.

For instance, the substrate 82 can be a silicon substrate while the thin film 85 is a thin monocrystalline silicon carbide layer from which a heteroepitaxial monocrystalline layer is formed. According to another example, the thin film 85 can be a GaN layer serving as a seed layer for performing homoepitaxial growth of GaN layers on a Si substrate.

As explained above, the motifs or trenches formed into the substrate 82 can be formed etched from the surface on which the thin film 85 is bonded as illustrated on figure 3B or from the opposite surface (see figure 4A).

The thin film 85 as well as subsequent layers which can be formed thereon may have a thickness in the range 0.1 µm to 2 µm.

One variation of the method is shown in Figures 4A and 4B. Reference numerals, which are identical to those shown in Figure 3A but with the addition of ten, designate similar or corresponding elements. An etched motif structure is produced in the substrate 90 intended to produce a thin layer 95 on the second substrate 92.

The techniques for preparing the plane of weakness and assembling the two substrates are identical to those described above in connection with Figures 3A and 3B.

The motifs do not appear in the final structure (Figure 4B), in contrast to Figure 3B. The plate or the substrate 90 can then be recycled, for example to transfer a new thin film to a further substrate.

This means that only one motif etching operations needs to be carried out for several transfer operations.

CLAIMS

1. A structure assembled from a film and a substrate, said film being produced from a second substrate by thinning, said film and said first substrate respectively having a first thermal expansion coefficient and a second thermal expansion coefficient which differs from the first, and respectively having first and second assembly faces, wherein motifs are formed in the substrate into the face opposite to that on which the film is bonded, said motifs being elastic or being flexible in a plane parallel to the first and second assembly faces so as to form a mechanical system for absorbing thermoelastic stresses generated at the assembly interface.

2. A structure according to claim 1, in which the motifs are in the form of studs or trenches or saw cuts.

3. A structure according to claims 1 or 2, in which the film and the substrate have thermal expansion coefficients that differ by at least 10% at ambient temperature.

4. A structure according to any one of claims 1 to 3, in which the substrate is constituted by one of the following materials: silicon, quartz, sapphire, silicon carbide, and glass.

5. A structure according to any one of claims 1 to 4, in which the film is constituted by one of the following materials: gallium arsenide, sapphire, germanium, gallium nitride, silicon, silicon-germanium (SiGe), indium phosphide, aluminum nitride, and silicon carbide.

6. A structure according to any one of claims 1 to 5, in which the film is in the form of a thin layer.

7. A structure according to claim 6, in which the thickness of the thin layer is in the range 0.1 μm to 2 μm.

8. A device for depositing materials by heteroepitaxy, wherein said device comprises the structure according to any one of claims 1 to 7.

9. A method for producing a film formed from a first material on a substrate formed from a second material, comprising:

- assembling together, first and second substrates respectively having a first thermal expansion coefficient and a second thermal expansion coefficient, which differs from the first, and respectively having first and second assembly faces, in which motifs have been formed into the face of the second substrate which is opposite to that bonded with the first substrate, said motifs being elastic or being flexible in a plane parallel to the first and second assembly faces so as to form a mechanical system for absorbing thermoelastic stresses generated at the assembly interface,

- separating a portion of one of the substrates or thinning one of the substrates, to leave a film on the other substrate.

10. A method according to claim 9, during which the set of the two assembled-together substrates undergoes a step in which the temperature is raised.

11. A method according to claims 9 or 10, in which the two substrates are assembled together by wafer bonding or by molecular contact or by adhesive bonding.

12. A method according to claims 9 or 10, in which the first substrate includes a zone of weakness.

13. A method according to claims 9 or 10, in which the second substrate includes a zone of weakness.

14. A method according to claims 12 or claim 13, in which the zone of weakness is produced by forming a porous layer.

15. A method according to claims 12 or claim 13, in which the zone of weakness is produced by ion implantation into the first substrate.

16. A method according to claim 9, in which separation or thinning of one of the substrates is carried out by polishing or etching.