

A METHOD OF OBTAINING A THIN FILM OF SEMICONDUCTOR
MATERIAL INCLUDING NOTABLY ELECTRONIC COMPONENTS

This invention relates to a process of obtaining a thin film of semiconductor material including notably electronic components. The thin film is obtained by separation of a part of a substrate of small thickness
5 in which, for example, one or several electronic components have been developed, from the rest of the substrate which has a relatively greater thickness. Depending on the application being considered, the invention also allows the transfer of the thin film
10 from its initial substrate to another substrate or support.

In microelectronics, it is often sought to produce electronic components in a thin semiconductor film supported on an insulating support or separated from
15 its support by an electrically insulating layer. Structures called Silicon On Insulator structures can be obtained from which electronic components can be developed. In order to obtain these structures one can use:

- 20 - heteroepitaxy methods, allowing, by crystalline growth, to grow a crystal, for example, of silicon in a thin film, on a monocrystalline substrate of another material whose lattice parameter is close to that of silicon, for example a sapphire (Al_2O_3) or a calcium
25 fluoride (CaF_2) substrate ;

- the method called "SIMOX" (a name currently used in the literature) which uses the ion implantation at a high dose of oxygen into a silicon substrate in order to create, in the volume of the silicon, a layer of silicon oxide separating a thin film of monocrystalline silicon from the mass of substrate ;

- other methods which use the principle of the thinning down of a wafer by combined mechanical and chemical or chemical abrasion.

10 These various methods of producing thin semiconductor films have disadvantages linked to the manufacturing techniques.

15 The heteroepitaxy methods are limited by the nature of the substrate: the lattice parameter of the substrate not being strictly exactly that of the semiconductor, the thin film includes many crystalline defects. Furthermore, these substrates are expensive and fragile and only exist with limited dimensions.

20 The SIMOX method requires ion implantation at a very high dose, which requires a very heavy and complex implantation machine. The throughput of these machines is low and it is difficult to envisage increasing it to an appreciable degree.

25 The thinning down methods are competitive from the point of view of homogeneity and quality only if they use the principle of the crash barrier to stop the etching which allows the thinning down of the wafer to be stopped as soon as the required thickness has been reached and to thereby guarantee homogeneity of
30 thickness. Unfortunately, the creation of this crash

barrier makes the process complex and can limit the use of the film in certain cases.

In order to remedy these disadvantages, in document FR-A-2,681,472, a process has been suggested
5 for the manufacture of a thin semiconductor film and its firm attachment to a support that consists of subjecting a wafer of the desired semiconductor material that includes a flat face to the following steps:

10 - a first implantation step by bombarding the flat face of said material with ions capable of creating, within the volume of the wafer and at a depth close to the penetration depth of said ions, a layer of gaseous microbubbles separating the wafer into a lower region
15 constituting the mass of the substrate and an upper region constituting the thin film, the ions being chosen from among the ions of rare gases or of hydrogen gas and the temperature of the wafer being maintained below the temperature at which the gas generated by the
20 implanted ions can escape from the semiconductor by diffusion ;

- a second step of bringing the flat face of the wafer into intimate contact with a support made up of at least one layer of rigid material. This intimate
25 contact may be created, for example with an adhesive substance, or with molecular adhesion through the effect of a preliminary preparation of the surfaces and possibly of a thermal and/or electrostatic treatment in order to encourage interatomic bonding between the
30 support and the wafer ;

- a third step of thermal treatment of the wafer-support assembly at a temperature over the temperature at which the implantation was carried out and sufficient to create, through a crystal rearrangement effect in the wafer and through the pressure of the microbubbles, a separation between the thin film and the mass of the substrate.

In this document, the following explanation is suggested of the different phenomena observed through experiment. Firstly, the first ion implantation step is conducted by presenting a flat face of a wafer of semiconductor material to a beam of ions, the plane of this flat face being either approximately parallel to a principal crystallographic plane in the case where the semiconductor material is perfectly monocrystalline or more or less inclined with respect to a principal crystallographic plane with the same indices for all the grains in the case where the material is polycrystalline.

This implantation is capable of creating a layer of gaseous microbubbles which will end up, at the end of a thermal treatment as a fracture zone. This layer of microbubbles thus created within the volume of the wafer, at a depth close to the mean penetration depth of the ions demarcates, within the volume of the wafer, two regions separated by this layer: one region intended to constitute the thin film and one region forming the rest of the substrate. By the expression "gaseous microbubble" one understands any cavity or microcavity generated by the implantation of ions of

hydrogen gas or rare gases in the material. The cavities may have a very flattened shape, that is to say of small height, for example of the order of a few interatomic distances, or may have a roughly
5 hemispherical shape or any other shape different from the two preceding shapes. These cavities may or may not contain a gaseous phase. During the third step, the thermal treatment is carried out at a temperature sufficient to create, through a crystal rearrangement
10 effect within the semiconductor material such as, for example through the effect of microcavity growth and or the effect of microbubble pressure, the fracture zone and the separation of the two regions.

According to the implantation conditions, after
15 implantation of a gas, such as, for example hydrogen, cavities or microbubbles are observable or not by transmission electronic microscopy. In the case of silicon, one can have microcavities, the size of which can vary from a few nm to several hundreds of nm.
20 Hence, particularly when the implantation temperature is low, these cavities are only observable during the thermal treatment stage, a step during which a nucleation of these cavities is brought about in order to allow the fracture between the thin film and the
25 rest of the substrate to occur at the end of the thermal treatment.

Furthermore, it appears that this method can be applied to all types of solid materials, crystalline or not. It is possible to apply this process to dielectric

materials, conductors, semi-insulators as well as to amorphous semiconductors.

The layer containing microbubbles or microcavities is a continuous layer in the sense that the
5 microbubbles or microcavities are present in sufficient density for the interaction between the microbubbles or microcavities to occur over the whole wafer and to lead to a fracture. If the implantation is locally masked, in an intentional or a non-intentional way, for
10 example, by a particle of the order of a μm , or less than 1 μm , the discontinuity resulting from it does not prevent the propagation of the fracture.

The object of all these methods is to obtain a thin semiconductor film on a support, in order to
15 subsequently develop electronic components in it through traditional processes. The method described in document FR-A-2,681,472 allows a solution to be provided to the problems inherent in prior techniques. However, in order to obtain a device made up of a
20 support coated with a thin semiconductor film in which electronic components have been developed, a step from the field of microelectronics is involved (an ion implantation step), followed by steps from the mechanical domain (a contacting step) and from the
25 thermal domain (a heat treatment step) in order to revert to steps relating to the microelectronic field (development of electronic components).

The inventors of this invention have thought to group together, in a consecutive way, certain steps
30 arising from the field of microelectronics, that is to

say up to the development of all or part of the electronic components, so as to optimise the manufacture or to allow the use of substrate that comprises the origin of the elements, for example the

5 electronic elements and to subsequently define a thin film on it. In order to achieve this result, it was necessary to resolve the following problem created by the fact that the development of electronic elements in a semiconducting layer causes the creation of a

10 heterogeneous medium, that is to say one made up of various materials (semiconductor, metals for the electrical contacts, insulators etc.) The implanted ions are therefore distributed at different depths in relation to the surface that receives the ions. As an

15 example, an implantation of hydrogen ions of energy 400 keV in silicon leads to the formation of microbubbles localised at a distance of about 4 μm from the surface offered to the ions. This distance is 3 μm for the same implantation in silicon having a 600 nm thick layer of

20 tungsten on the surface (see "The stopping and Range of Ions in Solids" by J. Ziegler et al., Pergamon, New York 1985). Consequently, in the case where the treated surface has different materials on the route of the ions, the microbubbles (or microcavities) are not all

25 localised in a layer sufficiently narrow for the interaction between the bubbles to occur over all of the surface of the wafer. The separation of the thin film from the rest of the semiconducting wafer cannot then take place in a satisfactory manner.

Another problem was created by the fact that an ion implantation through electrically active layers containing different doping and insulating materials can create defects that modify the characteristics of the components or render them unusable.

This invention allows one to provide a solution to these problems. It is proposed to carry out the ion implantation in relation to the nature of the materials passed through by the ions in such a manner that a continuous zone of microbubbles is obtained that allows a satisfactory cleavage (or fracture) between the thin film and the rest of the semiconducting wafer. In an advantageous way, several implantations at different energies can be carried out. The number of implantations is then fixed by the number of materials having different behaviours with respect to the implantation. Implantations at different energies allow the creation of a continuous zone of microbubbles situated at a constant depth in relation to the surface receiving the ions. As an example, for an implantation of hydrogen ions into silicon, the microbubbles must be localised in a zone whose thickness is less than 200 nm in order for the interaction between the bubbles to be able to take place during the subsequent thermal treatment and to lead to the separation of the regions situated on each side of the zone containing the microbubbles, in a continuous fashion, over the whole wafer.

The invention also provides a solution to the second possible problem resulting from the creation of

defects induced by the passage of ions through electrically active layers.

It is known that such defects can be corrected by the application of a thermal treatment. This is the subject of the reports "Physical and Electrical Properties of Laser-annealed Ion-implanted Silicon" by A. Gat et al. that appeared in the journal Appl. Phys. Lett. 32 (5), 1st March 1978 and "Pulsed Electron Beam Annealing of Ion-implantation Damage" by A.C. Greenwald et al. that appeared in the journal J. Appl. Phys. 50 (2), February 1979. If it is wanted to correct defects induced in the electronic components during the implantation step by a particular heat treatment before the separation step, this heat treatment must not then affect the zone containing the microbubbles since it would cause the separation of the two regions situated on each side of this zone. Contrary to this, this annealing must heat all of the zone containing the electronic components in order to remedy the induced defects. According to the invention, a transient annealing is therefore suggested, just after the ion implantation step, to heat the damaged regions in order to remove the defects but without heating the zone containing the microcavities.

In order to correct the defects induced by the implantation step, a total thermal treatment may also be carried out. If this treatment is carried out before the separation step, it must be carried out at an adequate temperature but one that is less than that necessary to obtain said separation, on the whole of

the structure, possibly with the support for the thin film. This heat treatment can also be carried out after the separation step, on the whole of the thin film, possibly with its support, and under these conditions, 5 the temperature used is not critical. Finally, this heat treatment can be combined with the heat treatment necessary for the separation of the thin film from the rest of the substrate, by adapting the temperature conditions and the duration. The choice between the 10 different possible heat treatments depends on the materials used and the components.

Therefore, an object of the invention is a method of obtaining a thin film from a substrate of semiconductor material, the thin film including at 15 least one element in a different material from that of said semiconductor material, produced on one face of the substrate and conferring on the thin film an heterogeneous structure, characterised in that it includes the following steps:

20 - implantation by bombardment of the face of said substrate including said element by ions capable of creating within the volume of the substrate, gaseous microbubbles, the implantation being carried out having regard to the element produced in such a way that a 25 continuous zone of microbubbles is obtained demarcating a region of small thickness, on the side of said face of the substrate and containing said element and a region of appreciably greater thickness formed from the rest of the substrate, the ions being chosen from among 30 the ions of rare gases or of hydrogen gas and the

temperature of the substrate being kept below the temperature at which the gas generated by the implanted ions is able to escape from the semiconductor by diffusion,

5 - then, thermal treatment of the substrate at a temperature that is sufficient to create, through the effect of a crystalline rearrangement effect in the substrate and the effect of microbubble pressure, a separation of the two regions situated on each side of
10 the zone of gaseous microbubbles, the region of small thickness constituting the thin film.

With a substrate made of a semiconductor material, one understands a substrate, at least the upper part of which, the part that will allow the thin film to be
15 produced, is semiconductive. The ion implantation can be carried out in one or several successive implantations, according to the number of materials present in the substrate having a different stopping power with respect to the implanted ions. Hence for an
20 element having the same stopping power as the substrate, an implantation in one step suffices, otherwise successive implantations are operated, the energy of the ions for each implantation being chosen in order to obtain said continuous zone of
25 microbubbles.

The method can additionally include a heat treatment step intended to correct the defects induced in said element during the implantation step.

In this case, and if the heat treatment step for
30 correcting defects induced in said element is carried

out before the heat treatment step intended to separate said regions from the substrate, this thermal correction treatment can be localised to the zone of the substrate containing said element. This thermal
5 correction treatment can be carried out by means of a laser beam.

Said element can be all or part of an electronic component or an electrical conductor.

According to a variation of the embodiment, before
10 the heat treatment step intended to separate said regions from the substrate, a step is provided in which said face of the substrate that includes said element is brought into intimate contact with a support. This bringing into contact can be carried out by any known
15 means, for example by molecular adhesion or by the use of an adhesive substance. This support may also include all or part of at least one electronic component and/or at least one electrical conductor.

The invention will be better understood and other
20 details and particular features will become apparent on reading the description that follows, giving for non-limitative exemplary purposes only, and accompanied by the appended drawings in which:

- Figure 1 is a sectional view of a semiconductor
25 substrate on the face of which an electronic component has been produced,

- Figure 2 illustrates the substrate of Figure 1 during a first ion implantation step,

- Figure 3 illustrates the same substrate during a
30 second ion implantation step.

- Figure 4 represents bringing the substrate, which has been subjected to the two ion implantation steps into intimate contact with a rigid support,

- Figure 5 shows the thin film rigidly fixed to the rigid support, such as results from the heat treatment step intended to separate the thin film from the rest of the substrate.

In the application example which will follow, the thin film will be fitted with an electronic component made up of three types of material: monocrystalline silicon for the active zones, silicon oxide as a dielectric and tungsten to provide the contacts. However the invention is not limited to the case of electronic components. It is also applicable to the manufacture of thin films including other elements which are, by nature, liable to modify the depth of implantation of the ions in the semiconductor material, for example metal strips used for electrical connection between circuits or components.

Figure 1 shows a semiconductor substrate 1 made of monocrystalline silicon, on the face 2 of which, an electronic component (a transistor 3) has been produced. The transistor 3 has been produced in accordance with a technique known to a skilled person. There is a well 4 doped in an appropriate manner in which a source 5 and a drain 6 have been created by doping. A gate 7a made of polycrystalline silicon and a gate oxide 7b have been formed on the face 2 of the substrate, between the source 5 and the drain 6. A layer 8 of silicon oxide has then been deposited and

the tungsten contacts 9 and 10, respectively for the source and the drain, have been produced through the oxide layer 8. Finally, a passivation layer 11, made of silicon oxide, has been deposited above the component 3, thus created.

According to the state of the surface of the semiconductor wafer obtained, it may be necessary to carry out mechanical chemical polishing of the upper face 12 so as to obtain a degree of roughness compatible with bringing this face into contact with a face of the rigid support during a later step. In effect, the topology of the surface on electronic components can be of the order of several hundreds of nm while the surface roughness to ensure sticking, for example by molecular adhesion, onto the rigid support must be less than about 0.5 nm in rms roughness. On this subject, one may make reference to T. ABE et al., Electrochemical Society Conference, Wafer Bonding Symposium, 1990, 61.

A first ion implantation step is then carried out, involving the bombardment of the wafer by an ion beam directed onto face 12, that is onto face 2 of the substrate 1 as shown by the arrow. The ions which might well be implanted have been specified in document FR-A-2,681,472.

Figure 2 illustrates this first ion implantation step. By using hydrogen ions of 400 keV energy, two different implantation depths are obtained. The implanted hydrogen that only passes through the silicon or the silicon oxide forms microcavities 21 at 4 μ m

depth with respect to face 12 of the wafer. On the other hand, implanted hydrogen of the same energy which passes through the zones containing a layer of tungsten (of mean thickness $0.6 \mu\text{m}$) forms microcavities at $3 \mu\text{m}$ depth with respect to face 12.

It is then necessary to proceed to a second ion implantation step as illustrated in Figure 3. An implantation of hydrogen ions of 470 keV energy, allows one to obtain a second profile of microcavities 23, 24 at a depth greater than the depth of the first profile of microcavities 21, 22. The implantation energies have been chosen in such a way that an alignment of microcavities 21 and 24 is obtained. Hence a continuous zone of microcavities or gaseous microbubbles is obtained that allows the demarcation of an upper region which will constitute the thin film and a lower region which will form the rest of the substrate.

The number of implantation steps is a function of the number of materials behaving differently with respect to the implantation. By behaving differently one understands the fact that the ions do not have the same mean depth of penetration in these materials.

Once the final implantation step is finished, one then proceeds, for example, to a transient annealing which only permits the zone containing the electronic component to be heated. This step is only necessary in the case where the component is disturbed by the implantation of the ions. By way of example, this annealing can be carried out by means of a laser beam directed onto the face 12, of wavelength below $0.4 \mu\text{m}$,

providing energy of 0.2 to 1 J/cm² during a period of 150 ns. Under these conditions, a temperature of the order of 800 to 900°C can be reached for a few microseconds. These temperatures are compatible with
5 the remedying of defects. This laser type annealing can be carried out either only once over the entire surface of the wafer or in several treatments, zone by zone.

Figure 4 illustrates the step of bringing the wafer into intimate contact with a rigid support 30.
10 This rigid support can be either a massive substrate (made, for example, of glass) or a substrate containing electronic components and/or electrical conductors. The presence of this rigid support will allow one to carry through the mechanics of the separation between the
15 upper region of substrate 1 and the lower region as disclosed in document FR-A-2,681,472.

However, in the case where the thickness of the thin film of semiconductor material is sufficiently great to have satisfactory rigidity, the presence of a
20 rigid support is not necessary and the polishing of face 12 of the wafer is no longer necessary either.

Then an isothermal heat treatment is carried out which heats, in a homogeneous way, the assembly made up of the wafer and the rigid support to a temperature
25 greater than the temperature at which the ion bombardment is carried out and sufficient to create, through a crystal rearrangement effect and through the pressure in the microbubbles, a separation of the substrate into two regions situated on each side of the
30 continuous zone of microcavities 21, 24. Thus, as shown

in Figure 5, a thin film 31 is obtained that includes an electronic component 3 supported by a rigid support 30.

Although the example described above only mentions
5 one electronic component, the invention is equally applicable to the creation of a thin film fitted with one or with several entirely or in part formed components.

CLAIMS

1. A method of obtaining a thin film from a substrate of semiconductor material, the thin film including at least one element of a different material from that of said semiconductor material, produced on
5 one face of the substrate and conferring on the thin film an heterogeneous structure, including the following steps:

- implantation by bombardment of the face of said substrate including said element by ions capable of
10 creating within the volume of the substrate gaseous microbubbles, the implantation being carried out having regard to the element produced in such a way that a continuous zone of microbubbles is obtained demarcating a region of small thickness, on the side of said face
15 of the substrate and containing said element and a region of appreciably greater thickness formed by the rest of the substrate, the ions being chosen from among the ions of rare gases or of hydrogen gas and the temperature of the substrate being kept below the
20 temperature at which the gas generated by the implanted ions is able to escape from the semiconductor by diffusion,

- then, thermal treatment of the substrate at a temperature that is sufficient to create, by a
25 crystalline rearrangement effect in the substrate and the effect of microbubble pressure, a separation of the



two regions situated on each side of the zone of gaseous microbubbles, the region of small thickness constituting the thin film.

2. A method according to Claim 1 in which during
5 the ion implantation step, successive implantations are operated, the energy of the ions for each implantation being chosen in order to obtain said continuous zone of microbubbles

3. A method according to Claim 1 further
10 comprising a thermal treatment step intended to correct the defects induced in said element during the implantation step.

4. A method according to Claim 3, in which the thermal treatment step for correcting the defects
15 induced in said element being carried out before the thermal treatment step intended to separate said regions of the substrate, this thermal correction treatment is localised to the area of substrate containing said element.

20 5. A method according to Claim 4, in which the thermal correction treatment is carried out using a laser beam.

6. A method according to Claim 3, in which the thermal correction treatment of defects induced in said
25 element being carried out before the thermal treatment step, intended to separate said regions of the substrate, this thermal correction treatment consists of bringing the substrate to a temperature sufficient to obtain the remedying of the defects but is less



than the temperature required to obtain the separation of said two regions.

7. A method according to Claim 3, in which the thermal correction treatment of defects induced in said
5 element is carried out after the thermal treatment step intended to separate the said regions of the substrate.

8. A method according to Claim 3, in which the thermal correction treatment of defects induced in said element and the thermal treatment step intended to
10 separate the said regions of the substrate are combined into one and the same thermal treatment operation.

9. A method according to Claim 1 in which said element is all or part of an electronic component or an electrical conductor.

15 10. A method according to Claim 1 in which, before the thermal treatment step intended to separate the said regions of the substrate, a step is provided in which said face of the substrate including said element is brought into intimate contact with a support.

20 11. A method according to Claim 10 in which, said support includes all or a part of at least one electronic component and/or at least one electrical conductor.