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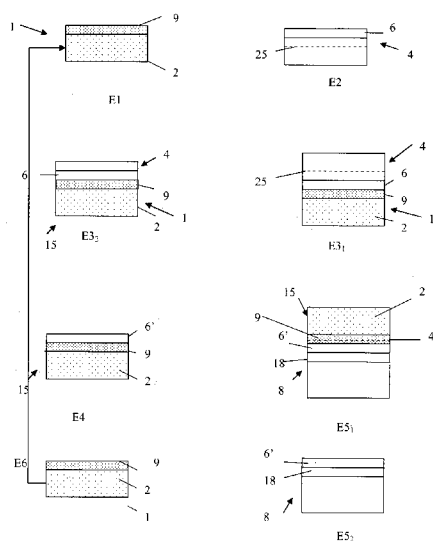


Figure 1

(57) Abstract: The invention relates to a method for manufacturing a semiconductor device, characterized in that it comprises: a first step (E1) consisting in forming a support substrate (1) comprising a first porous layer (2), a second porous layer (9), with a porosity lower than the porosity of the first layer (2), a second step (E2) consisting in providing a donor substrate (4), comprising, a useful layer (6), a third step (E3) consisting of bonding the support substrate (1) and the donor substrate (4), transferring at least a portion of the useful layer (6) to form a semiconductor device (15), a fourth step (E4) consisting of treating said semiconductor device (15) in such a way as to deform by dilation or contraction at least the first porous layer, said deformation inducing strain in the useful layer (6).

METHOD FOR MANUFACTURING A SEMICONDUCTOR SUBSTRATE AND A SEMICONDUCTOR SUBSTRATE

GENERAL TECHNICAL FIELD

The invention relates to a method for manufacturing a semiconductor substrate, and to a semiconductor substrate.

STATE OF THE ART

Silicon on insulator (SOI) substrates are widely used in the microelectronics industry.

In particular, strained silicon on insulator (sSOI) substrates are of major interest for the manufacture of electronic components, notably due to the fact that sSOI substrates offer an improved mobility of electrons and holes, and thus greater performance.

A strained layer of a material is a layer of a material whose crystallographic structure is strained under tension or compression compared to the natural crystallographic structure of the material.

Strained silicon with the lowest possible defect density is generally searched.

One method for manufacturing strained silicon, known in the state of the art, consists in depositing by epitaxy a strained layer of silicon on a first layer whose lattice parameter is different than the lattice parameter of relaxed silicon. This first layer can be a buffer layer whose composition can vary with its thickness.

Another known method for manufacturing strained silicon consists in using a substrate comprising a layer of porous silicon in contact with a surface layer of nonporous silicon, and dilating the layer of porous silicon to induce strain in the surface layer of silicon.

"Porous layer of a semiconductor material," for example a layer of porous silicon, refers to a layer of a microstructured material comprising pores.

A disadvantage common to known methods of manufacturing sSOI, and more generally strained useful layers, is that they are expensive and take a long time to implement.

The invention aims to provide at least partial freedom from this disadvantage.

Moreover, the known processes of the prior art do not make it possible to obtain thin layers of a strained semiconductor material in contact with the porous layer. However, thin layers, such as, for example, layers of strained silicon roughly 50 nm thick, are necessary for the manufacture of numerous electronic devices.

The invention thus aims to mitigate, at least partly, these disadvantages.

PRESENTATION OF THE INVENTION

The invention proposes a method for manufacturing a semiconductor device, characterized in that it comprises a first step consisting in forming a semiconductor support substrate comprising a first porous layer composed of a semiconductor material, and a second porous layer composed of a semiconductor material, with a porosity lower than the porosity of the first layer, a second step consisting in providing a semiconductor donor substrate, comprising a useful layer composed of a semiconductor material, and a third step consisting in bonding the support substrate and the donor substrate, and transferring at least a portion of the useful layer from the donor substrate to the support substrate, to form a semiconductor device.

The invention is advantageously supplemented by the following characteristics, taken alone or in any technically possible combination:

- the method comprises a fourth step consisting of treating said semiconductor device in such a way as to deform by dilation or contraction at least the first porous layer of the support substrate, said deformation inducing strain in the useful layer, then referred to as the strained useful layer;

- the useful layer transferred from the donor substrate to the support substrate has a thickness between 10 nm and 1 μ m;
- the third step of transferring the useful layer of the donor substrate to the support substrate comprises the steps of: creation of an embrittlement zone in the donor substrate, prior to bonding the support substrate and the donor substrate, by ion implantation, and creating a fracture at said embrittlement zone, to detach the support substrate from the donor substrate;
- transferring the useful layer from the donor substrate to the support substrate comprises the use of a dismountable donor substrate;
- the second step comprises the supply of a donor substrate further comprising a semiconductor confinement layer, said confinement layer possessing a chemical composition different than the useful layer, and the third step consisting of transferring the useful layer from the donor substrate to the support substrate comprises the steps consisting of introducing ions into the donor substrate, bonding the support substrate and the donor substrate, subjecting the support substrate and the donor substrate to heat treatment comprising an increase in temperature, during which the confinement layer attracts ions and concentrates them within said confinement layer, and detaching the support substrate from the donor substrate by fracturing said confinement layer;
- the method comprises a fifth step consisting of transferring at least a portion of the useful strained layer from the semiconductor device to a receptor substrate, and a sixth step consisting in reusing the support substrate, at least in the second and third steps of the manufacturing method, for the manufacture of a novel semiconductor device, or at least in the second, third and fourth steps of the manufacturing method, for the manufacture of a novel semiconductor device, or at least in the second, third, fourth and fifth steps of the manufacturing method, for the manufacture of a novel receptor substrate.

The invention also relates to a method comprising a first step consisting in forming a semiconductor support substrate comprising a porous layer composed of a semiconductor material, a second step consisting in providing a semiconductor donor substrate, comprising a useful layer composed of a semiconductor material, a third step consisting in forming an oxide layer in contact with the porous layer and/or contact with the useful layer, a fourth step consisting in bonding the support substrate and the donor substrate at the oxide layer, and transferring at least a portion of the useful layer from the donor substrate to the support substrate, to form a semiconductor device, a fifth step consisting of treating said semiconductor device in such a way as to deform the porous layer by dilation or contraction, said deformation inducing strain in the useful layer, forming a strained useful layer, and a sixth step consisting of transferring at least a portion of the strained useful layer from the semiconductor device to a receptor substrate, said transfer being configured to enable the partial or total preservation of the porous layer of the support substrate.

This method is advantageously supplemented by the following characteristics, taken alone or in any technically possible combination:

- the sixth step consists of creating an embrittlement zone in the semiconductor device, bonding the semiconductor device and the receptor substrate, and creating a fracture at said embrittlement zone, to detach the semiconductor device from the receptor substrate;
- the useful layer transferred from the donor substrate to the support substrate has a thickness between 10 nm and 1 μ m;
- the fourth step of transferring the useful layer from the donor substrate to the support substrate comprises the steps of: creating an embrittlement zone in the donor substrate, prior to bonding the support substrate and the receptor substrate, by ion implantation, creating a fracture at said embrittlement zone, to detach the support substrate from the receptor substrate;

- the transfer of the strained useful layer from the donor substrate to the support substrate comprises the use of a dismountable donor substrate;
- the second step comprises the supply of a donor substrate further comprising a semiconductor confinement layer, said confinement layer possessing a chemical composition different than the useful layer, and the fourth step consisting of transferring the useful layer from the donor substrate to the support substrate comprises the steps consisting of introducing ions into the donor substrate, bonding the support substrate and the donor substrate, subjecting the support substrate and the donor substrate to heat treatment comprising an increase in temperature, during which the confinement layer attracts ions and concentrates them within said confinement layer, and detaching the support substrate from the donor substrate by fracturing said confinement layer;
- the method comprises a seventh step consisting in reusing the support substrate comprising the porous layer, at least in the second and fourth steps of the manufacturing method, for the manufacture of a novel semiconductor device, or at least in the second, fourth and fifth steps of the manufacturing method, for the manufacture of a novel semiconductor device, or at least in the second, fourth, fifth, and sixth steps of the manufacturing method, for the manufacture of a novel receptor substrate.

The invention also relates to a semiconductor device comprising successively a first porous layer composed of a semiconductor material, a second porous layer composed of a semiconductor material, and with a porosity lower than the porosity of the first layer, and a useful layer composed of a semiconductor material, having a thickness between 10 nm and 1 μ m.

The invention also relates to a semiconductor device comprising successively a first porous layer composed of a semiconductor material, an

oxide layer in contact with the first porous layer, and a useful layer composed of a semiconductor material, having a thickness between 10 nm and 1 μm .

In these devices, the useful layer is advantageously strained.

The invention makes it possible to obtain thin layers of semiconductor material on a porous semiconductor layer, which in the end makes it possible to manufacture thin strained layers of semiconductor material.

The invention further makes it possible to reduce the manufacturing lead times of strained layers with good crystalline quality, as well as associated manufacturing costs.

PRESENTATION OF THE FIGURES

Other characteristics, goals and advantages of the invention will arise from the following description, which is purely illustrative and nonrestrictive, and which must be considered in reference to the appended drawings wherein:

- Figure 1 is a schematic representation of a first embodiment of the method according to the invention;
- Figure 2 is a schematic representation of an electrochemical anodization method;
- Figure 3 is a schematic representation of another electrochemical anodization method;
- Figure 4 is a schematic representation of an embodiment of the transfer of the useful layer;
- Figure 5 is a schematic representation of ion concentration in a substrate, in the case of diffusion and implantation;
- Figure 6 is a schematic representation of a second embodiment of the method according to the invention;
- Figure 7 is a schematic representation of an embodiment of the transfer of the useful layer, identical to that of Figure 4;

- Figure 8 is a schematic representation of another inventive manufacturing method.

DETAILED DESCRIPTION

The steps of a first embodiment of a method for manufacturing a semiconductor device of the invention are represented in Figure 1.

The expression "semiconductor substrate or device" refers to a structure comprising at least one layer of one or more semiconductor materials.

"Strained layer" refers to any layer of a semiconductor material whose crystallographic structure is strained under tension or compression, compared to the natural crystallographic structure of the material. For example, it is possible to obtain strained layers during crystal growth, such as epitaxy, which modifies the crystal lattice, in particular in the direction of growth.

Conversely, "relaxed layer" refers to any layer of a semiconductor material which has a crystallographic structure free of any external strain applied, *i.e.*, with a lattice parameter identical to the lattice parameter of a layer of this material in massive single-crystal form.

The method comprises a first step E1 consisting in forming a semiconductor support substrate 1 comprising a first porous layer 2 composed of a semiconductor material, and a second porous layer 9 composed of a semiconductor material, said second layer 9 having a porosity lower than the porosity of the first layer 2.

The first and second layers consist of a semiconductor material, which includes a single material for each layer or several materials for each layer.

The first and second layers, for example, consist of silicon, germanium or a group III-V alloy (alloy of an element from the third column and an element from the fifth column of the periodic table of the elements).

In one embodiment, the first and second layers are composed of the same semiconductor material.

A porous layer of a semiconductor material is a layer of a microstructured material comprising pores. The pores constitute the voids between the material's crystallites.

The porosity of the material is defined as the fraction of unoccupied volume (pores) within the material. Other parameters can be used to characterize the porous layer (pore size, morphology, thickness, pore diameter, crystallite size, specific surface area, etc.).

For example, if the material is silicon, it is porous silicon, generally classified in three categories by those persons skilled in the art:

- macroporous silicon, generally obtained from n-type silicon, and lightly doped;
- mesoporous silicon, generally obtained from heavily doped p⁺ silicon, and
- nanoporous silicon, generally obtained from p-type silicon, and lightly doped.

The porosity P of a porous layer of semiconductor is defined as the fraction of unoccupied volume within the porous layer. It is written

$$P = \frac{\rho - \rho_{po}}{\rho},$$
 with ρ the density of the nonporous material and ρ_{po} the

density of the porous material. It generally varies between 10% and 90%.

Other parameters can be used to characterize the porous layer (pore size, morphology, thickness, pore diameter, crystallite size, specific surface areas, etc.).

As an example, if the first layer and the second layer are made of silicon, the first layer 2 will be manufactured with a porosity between 30% and 70%, and the second layer 9 with a porosity between 5% and 30%.

The support substrate 1 can be obtained in various ways.

Advantageously, it involves a step of electrochemical anodization of the support substrate 1.

One embodiment of such electrochemical anodization is illustrated in Figure 2.

Support substrate 1 is placed in an enclosure 10 comprising an electrolyte 11.

The electrolyte 11 is for example a solution comprising hydrofluoric acid (HF).

An anode 12 and a cathode 13, plunged into the electrolyte 11, are supplied by a source of electrical power 14.

An electrical current is applied between the anode 12 and the cathode 13 via the source of electrical power 14.

To obtain a first porous layer 2, and a second porous layer 9 having a lower porosity, a solution consists in doping the first and second layers differently. In particular, it is advantageous to dope p the first layer 2 and the second layer 9, with however doping for the first layer above the second layer.

Another solution, complementary or alternative, consists in adjusting the density of the electrical current applied by the source of electrical power 14.

In Figure 3, another embodiment of electrochemical anodization is represented, called a "double-bath" unit.

The enclosure 10 comprises two semi-reservoirs each comprising an electrolyte 11, for example an HF/ethanol mixture.

The support substrate 1 plays the role of barrier between the two semi-reservoirs, which are not interconnected.

The enclosure 10 is in general a Teflon[®] tank and comprises O rings 16 arranged between the support substrate 1 and the electrolyte 11.

As for the preceding embodiment, the two electrodes 12 and 13, for example of platinum, constitute the anode and the cathode and are fed by a source of electrical power 14.

Adjusting the density of the electrical current, and/or suitably choosing the doping for the layers of the support substrate 1, make it possible to obtain this differentiated porosity between the first layer 2 and the second layer 9.

In all cases, the results of the treatment for rendering the first and second layers porous depend on various parameters, such as doping type and degree, crystalline orientation of the layer's material, current density, electrolyte composition and concentration, temperature and anodization time.

Other solutions are possible.

At the end of anodization, the support substrate 1 is rinsed.

In another embodiment of this first step E1, the support substrate 1 is already porous, prior to step E1, and the first and second layers are formed by a selective "porosification" operation in order to obtain a first porous layer 2 and a second porous layer 9 with a porosity lower than the first layer.

In another embodiment of the first step, the second porous layer is transferred in contact with the first porous layer, by bonding or any other method known to those persons skilled in the art.

The method comprises a second step E2 consisting in providing a semiconductor donor substrate 4, comprising a useful layer 6 composed of semiconductor material. The semiconductor material of the useful layer 6 is advantageously silicon, but it can be other elements, such as germanium, or a group III-V alloy, or any semiconductor material required for a given application.

The method further comprises a third step E3 consisting in bonding (step E3₁) the support substrate 1 and the donor substrate 4 at the second porous layer 9 of the support substrate 1 and the useful layer 6 of the receptor substrate 4, and transferring (step E3₂) at least a portion of the useful layer 6 from the donor substrate 4 to the support substrate 1, to form a semiconductor device 15.

The bonding can be direct, by bringing into contact the surfaces of the second layer 9 and the useful layer 6, or there can be in addition an intermediate oxide layer.

Advantageously, the third step E3 of transferring the useful layer 6 of the donor substrate 4 to the support substrate 1 comprises the steps of:

- creating an embrittlement zone 25 in the donor substrate 4, prior to bonding the support substrate 1 and the receptor substrate 4, by ion implantation, and
- creating a fracture at said embrittlement zone 25 to detach the support substrate 1 from the receptor substrate 4.

The embrittlement zone 25 is created by implanting ions, such as hydrogen or helium ions, or a combination of hydrogen/helium, or helium/boron or hydrogen/helium/boron.

The transfer step is in general carried out according to the Smart Cut™ technique.

Alternatively, the transfer of at least a portion of the useful layer 6 of the donor substrate 4 to the support substrate 1 comprises the use of a dismountable donor substrate 4.

Advantageously, it is a dismountable silicon on insulator (SOI) donor substrate 4.

At the end of the third step, it is possible to remove the remainder of the substrate 4 present above the useful layer 6, for example by selective etching.

Advantageously, the layer 6 composed of semiconductor material transferred from the donor substrate 4 to the support substrate 1 has a thickness between 10 nm and 1 μ m.

At the end of the third step, a semiconductor device 15 successively comprising the following is available:

- a first porous layer 2 composed of semiconductor material,
- a second porous layer 9 composed of semiconductor material, with a porosity lower than the porosity of the first layer 2, and
- a useful layer 6 composed of semiconductor material, with a thickness between 10 nm and 1 μ m.

By virtue of the invention, a thin layer of semiconductor material transferred to a porous substrate is thus available, which is highly advantageous with respect to the difficulty for obtaining thin layers of a

semiconductor material on a porous substrate, notably due to problems of adhesion of layers on a porous substrate.

Advantageously, the first porous layer 2 and the second porous layer 9 are made of silicon, *i.e.*, the support substrate 1 is a silicon substrate. Advantageously, the useful layer 6 is also made of silicon. Other materials for these layers include, for example SiGe or Ge.

The transfer of the useful layer 6 of the donor substrate 4 to the support substrate 1 can be implemented by having constituted in the donor substrate 4 an embrittlement zone, at which a fracture could be created to carry out the transfer.

The embrittlement zone can be constituted by implantation in the donor substrate, as was described above.

In this case, ions are accelerated in the direction of the surface of the donor substrate. The average penetration depth of the atoms in general is between 100 Å and 1 µm – this depth being determined according to the species implanted and the implantation energy. In the case of implantation, the doping has an implantation peak in the donor substrate. The implanted ions have an energy selected to enable them to cross the donor substrate material. The implantation peak depends on ion energy.

It can also have been constituted differently, for example in the manner described below.

An embodiment of the third step E3 of the transfer of the useful layer 6 of the donor substrate 4 to the support substrate 1 is thus described.

This embodiment is illustrated in Figure 4.

In this embodiment, the second step E2 comprises the supply of a donor substrate 4 further comprising a semiconductor confinement layer 30, said confinement layer 30 having a different chemical composition than the useful layer 6. This confinement layer 30 can be integrated in a confinement structure described below.

The role of this confinement layer 30 is to attract the ions introduced subsequently in the donor substrate (for example by diffusion) during thermal annealing carried out on the donor substrate after this introduction,

and during which the ions will preferentially migrate toward the confinement layer 30.

The confinement structure comprising the confinement layer 30 is generally obtained by epitaxy, and is formed during the step E2 of formation of the donor substrate 4.

Epitaxy makes it possible to precisely control the thickness of the confinement layer 30, and makes it possible to obtain it in thin layers.

Moreover, epitaxy makes it possible to preserve the crystallinity of the donor substrate 4.

The confinement layer material is advantageously selected from SiGe, doped or not, or doped silicon. Other materials notably include boron-doped germanium, boron-doped SiC or InGaN.

Doping with boron, arsenic or antimony, for example, can be implemented.

Other materials and other dopants can be used. In all cases, the confinement layer consists of a material with a different chemical composition than the useful layer 6 to be transferred, which includes a difference at least in the proportion of the chemical elements (for example, SiGe with a different proportion of germanium), or in the type of material (for example, SiGe for layer 30 and Si for layer 6), or in the fact that the confinement layer has higher doping than the layer 6 to be transferred (for example, boron-doped SiGe for layer 30, and undoped or less-doped SiGe for layer 6), or a combination of one or more of these differences.

To enable the transfer of the useful layer 6, the third transfer step S6 comprises a step E301 of introducing the ions 24 into the donor substrate 4. These ions make it possible to create an embrittlement zone in the donor substrate 4, at which a fracture can occur.

These are advantageously hydrogen ions or helium ions, or a combination of said ions.

This introduction can be carried out in various ways.

Advantageously, introduction of the ions 24 into the donor substrate 4 is carried out by diffusion of the ions 24 into the donor substrate 4 following

immersion of the donor substrate 4 into plasma comprising said ions. It is specified that this introduction of the ions 24 into the donor substrate 4 can be implemented by techniques other than diffusion, for example by implantation.

The donor substrate 4 plunged into the plasma is subjected to electrical pulses. The positive ions present in the plasma are then accelerated toward the surface of the substrate in which they are introduced. Since plasma surrounds the substrate, the entire surface receives ions simultaneously.

Another advantage of this ion introduction is its ability to be applied on an industrial scale, as well as its reduced implementation time.

Another advantage of this ion introduction is that the ion diffusion zone in the donor substrate is highly concentrated, on the order of a few nanometers in thickness according to the normal direction in the principal surfaces of the substrate (between 10 nm and 200 nm, for example).

The introduction of ions by plasma diffusion thus makes it possible to obtain good results in the transfer step, insofar as this technique notably makes it possible to enrich the donor substrate 4 in ions with low energy (between 3 and 25 keV) and at a high dose (between $5 \cdot 10^{16}$ and $2 \cdot 10^{17} \text{ cm}^{-2}$) in a region of low depth (a few tens of nanometers to roughly 200 nanometers as was called to mind above), which is not always accessible by an implantation technique. This is advantageous in order to subsequently transfer thin layers of the useful layer 6 to be transferred. As explained below, this is advantageous to reduce defects and roughness present in the transferred layer.

Indeed, even when the region is accessible by implantation, the high energy of the ions in the implantation method leads to the introduction of crystal defects in the useful layer 6 to be transferred, making its subsequent use more difficult.

Figure 5 illustrates the concentration profile of the ions 24 in the donor substrate 1 as a function of depth in the donor substrate 4, in the case of diffusion (plot 26) and in the case of ion implantation (plot 27).

The third transfer step further comprises a step E302 consisting in bonding donor substrate 4 and support substrate 1.

This bonding is carried out by bringing into contact the free surfaces of the donor substrate and the receptor substrate. Generally, these surfaces have been cleaned beforehand to ensure the molecular adhesion of said surfaces.

The third transfer step then comprises a step E303 of heat treatment of the donor substrate 4 and the support substrate 1, consisting of subjecting them to an increase in temperature.

If a confinement layer has been constituted, said layer is prepared in one or more materials suited to the attraction of the ions introduced into the substrate toward said confinement layer, during this rising-temperature heat treatment. Heat treatment temperatures are typically between 200 °C and 700 °C.

For example, if the confinement layer material is boron-doped silicon, and the ions introduced into the donor substrate are hydrogen ions, the chemical interactions between boron and hydrogen will notably make it possible to attract hydrogen ions in the confinement layer. Another factor of ion attraction can result from the difference in strain (tension or compression).

Thus, during the heat treatment of the donor substrate and the receptor substrate, the confinement layer attracts ions and concentrates them within said confinement layer.

Another function of this heat treatment can be to strengthen the bonding energy between the donor substrate and the receptor substrate.

Annealing is carried out in such a way that different effects take place:

- the bonding energy between the donor substrate and the receptor substrate is increased,
- the ions concentrate in the confinement layer until reaching a critical concentration,
- these ions create cavities, which will coalesce,

- the pressure in these cavities increases until it causes a fracture in the confinement layer, which makes it possible to separate the donor substrate from the receptor substrate.

These four effects can be obtained during a single thermal annealing, or during separate individual thermal annealings.

Thus, the step following heat treatment is a step E304 consisting of detaching the donor substrate 4 from the support substrate 1 by fracturing said confinement layer 30.

The useful layer 6, all or in part, is thus transferred.

The support substrate 1 is then treated by cleaning and polishing (CMP or other), in order to remove the remaining material of undesirable layers. In particular, the residual confinement layer is transferred with the strained layer of the semiconductor.

An advantage of the transfer method implementing the constitution of a confinement layer is that the fracture is highly localized and only or nearly only takes place at the confinement layer.

Typically, the post-fracture AFM roughness obtained without the confinement layer is on the order of 3 to 6 nm, whereas the confinement layer makes it possible to reduce this roughness to values on the order of 0.5 to 1 nm. Thus, the propagation of defects toward the useful layer to be transferred is avoided. Indeed, in the case of traditional transfer by ion implantation and fracture at an embrittlement zone without the use of a confinement layer, it is common for defects to appear in the substrate after fracture. This is notably due to the extensive presence of ions in the substrate, which induces a fracture that is poorly localized, and thus a higher roughness.

The useful layer 6 transferred in accordance with the present method is thus less rough. For example, in the case of a donor substrate 4 comprising a silicon layer 6 to be transferred and a confinement layer 30 made of boron-doped silicon, a transferred silicon layer roughness of 5 Å (RMS) can be obtained.

Moreover, it is often necessary to transfer the useful layers 6 in a thin layer (between 20 nm and 500 nm, for example). Indeed, it is known that a compromise exists between the strain present in the layer and the thickness of said layer. For a given strain, there is one thickness beyond which the strain is released by the appearance of defects.

This embodiment of the third step thus makes it possible notably to transfer the useful layers 6 with a thickness between 10 and 200 nm.

Advantageously, a confinement layer with a thickness between 2 and 20 nm is used. The thinner the confinement layer, the more localized the fracture. For example, a confinement layer roughly 4 nm thick will make it possible to confine the fracture in this zone.

With respect to the thinness of the confinement layer, this disrupts little or not at all the lattice parameter of the donor substrate.

Generally, it is possible to use a confinement structure, comprising a confinement layer 30 such as described above, and two protective layers, arranged in contact with and on both sides of the confinement layer, each of these protective layers being made of a semiconductor material of a different chemical composition than that of the confinement layer material. It is understood that "different chemical composition" refers to the fact that the materials are different, or that they have different proportions of chemical elements, and/or that they have been doped with a different dopant.

The transfer is made with the confinement structure in a manner similar to that described above for the confinement layer.

These protective layers make it possible to advantageously further limit the propagation of defects resulting from the fracture. These notably play the role of protective shield for the useful layer 6 to be transferred, and confine defects able to propagate toward the useful layer 6 following fracturing of the confinement layer.

Examples of protective layers include, but are not limited to:

- protective layer material: $\text{Si}_{(1-x)}\text{Ge}_x$; confinement layer material: $\text{Si}_{(1-y)}\text{Ge}_y$ (advantageously, the difference between x and y is at least 3%, preferably greater than 5%, even 10%), boron-doped SiGe or boron-

doped silicon. Mention can also be made of the case in which the protective layers are of SiGe and the confinement layer is of boron-doped silicon, just as the case in which the protective layers are of SiGe and the confinement layer is boron-doped Ge;

- protective layer material: silicon; confinement layer material: $\text{Si}_{(1-y)}\text{Ge}_y$, boron-doped SiGe or boron-doped silicon;
- protective layer material: germanium; confinement layer material: boron-doped SiGe, boron-doped silicon, boron-doped germanium or SiGe;
- protective layer material: SiGe; confinement layer material: boron-doped SiC;
- protective layer material: AlGaN; confinement layer material: InGaN, doped (Si, Mg) or not;
- protective layer material: AlGaAs; confinement layer material: InGaAs, doped (Si, Zn, S, Sn) or not.

Advantageously, the materials of the protective layers are also suited to the attraction of ions introduced into the donor substrate toward the confinement layer, during heat treatment in which the temperature of said donor substrate increases, such as, for example, of doped or undoped SiGe making it possible to attract hydrogen ions.

Moreover, or alternatively, it is advantageous that at least one of the protective layers is an etch-stop layer, composed of a material that enables selective chemical etching of the protective layer with respect to the useful layer 6. In general, a protective layer is in contact with the useful layer 6.

This makes it possible to implement a step consisting of selectively etching the protective layer present on the support substrate 1 after detachment of the donor substrate 4.

Furthermore, or alternatively, one of the protective layers can be a chemical etch-stop layer, composed of a material enabling selective chemical etching of the protective layer with respect to the inferior layers of the donor substrate 4.

The method can comprise a step consisting of selectively etching the protective layer present on the donor substrate after fracture, which enables the donor substrate to be reused.

In one embodiment of the third step E3, it comprises a preliminary step of forming a layer of oxide (SiO_2 , for example) in contact with the second layer 9 of the support substrate 1 and/or the useful layer 6 of the donor substrate 4.

The oxide layer makes it possible to further facilitate the bonding of the support substrate 1 and the donor substrate 4 with a view to transferring at least a portion of the useful layer 6.

In this case, at the end of the third step, a semiconductor device 15 further comprising an oxide layer between the second porous layer 9 and the useful layer 6 is obtained.

The method can further comprise a fourth step E4 consisting of treating said semiconductor device 15 in such a way as to deform by dilatation or contraction at least the first porous layer 2 of the support substrate 1, said deformation inducing strain in the useful layer 6, then referred to as the strained useful layer 6'.

Deformation of the first porous layer 2 can be either dilation or contraction. Dilation corresponds to an expansion of material, *i.e.*, a deformation under tension of material, whereas contraction corresponds to a retraction of material, *i.e.*, a deformation under compression of material.

The fourth step E4 can, for example, comprise a step of thermal oxidation of the semiconductor device 15.

In this case, the semiconductor device 15 is subjected to heat treatment (for example between 200 °C and 800 °C), in an oxidizing atmosphere (atmosphere comprising for example O_2 , or NO_2 , etc.).

This causes deformation of the first porous layer 2, and thus strain in the useful layer 6, then referred to as strained useful layer 6'.

At this stage, a semiconductor device 15 comprising a strained useful layer 6' is thus available. By virtue of the method of the invention, it is thus

possible to obtain a very thin strained layer of semiconductor material arranged on a porous substrate.

The method can comprise a fifth step E5 consisting of transferring at least a portion of the strained useful layer 6', from the semiconductor device 15 to a receptor substrate 8.

Advantageously, the step E5 consisting of transferring at least a portion of the strained useful layer 6' from the semiconductor device 15 to a receptor substrate 8 comprises the following steps:

- creating an embrittlement zone 40 in the semiconductor device 15, by ion implantation,
- bonding (step E5₁) the semiconductor device 15 and the receptor substrate 8, and
- creating a fracture (step E5₂) at said embrittlement zone 40, to detach the semiconductor device 15 from the receptor substrate 8.

Before bonding, the surfaces to be bonded together are generally cleaned.

The embrittlement zone 40 can be created in the strained useful layer 6', in the second porous layer 9, in the first porous layer 2 or in other layers. It is advantageous to create the embrittlement zone in the second porous layer, which is less rough and stiffer than the rest of the device 15. The presence of this second porous layer is thus advantageous for the implementation of a Smart Cut™ transfer involving the creation of an embrittlement zone.

The embrittlement zone 40 is created by implantation of ions, such as hydrogen or helium or boron ions or a combination of hydrogen with the latter two ions.

The transfer step is in general carried out according to the Smart Cut™ technique.

Regardless of the mode of transfer chosen, it is advantageous to use a transfer that preserves the entire first porous layer 2. This is, for example, carried out by creating the embrittlement zone outside the first porous layer 2. Moreover, it is possible to choose a transfer that also makes it possible to

preserve, entirely or partially, the second porous layer 9 by creating the embrittlement zone outside of this second layer.

The receptor substrate 8 advantageously comprises an oxide layer 18, which makes it possible to obtain at the end of the fifth step a strained silicon on insulator (sSOI) receptor substrate 8, in the case where the strained layer 6' is made of silicon.

Another advantage of the inventive method is to partly or entirely preserve the support substrate 1 comprising the first and second porous layers.

The transfer of the strained useful layer 6' to the receptor substrate 8 can also be carried out in accordance with the transfer explained in relation to Figure 4, which relies on the use of a confinement structure or a confinement layer in the device 15 and ion introduction, advantageously carried out by diffusion in plasma, said confinement structure or confinement layer making it possible to attract and concentrate ions during a temperature increase, to create a fracture that induces fewer defects in the useful layer 6' to be transferred. The details of this type of transfer will not be described again.

The method comprises advantageously a sixth step E6 consisting in reusing the support substrate 1 at least in the second and third steps E2 and E3 of the manufacturing method, for the manufacture of a novel semiconductor device 15. This novel semiconductor device 15 comprises a first porous layer of a semiconductor material, a second porous layer of a semiconductor material, with a porosity lower than the first layer, and a novel useful layer 6 of a semiconductor material.

Advantageously, the sixth step E6 consists in reusing the support substrate 1 at least in the second, third and fourth steps of the manufacturing method, for the manufacture of a novel semiconductor device 15. In this case, the novel semiconductor device 15 comprises a strained useful layer 6' of a semiconductor material.

Advantageously, the sixth step E6 consists in reusing the support substrate 1 at least in the second, third, fourth and fifth steps of the manufacturing method, for the manufacture of a novel receptor substrate 8.

In general, the sixth step E6 comprises a preliminary step of treating the support substrate 1 with a chemical solution, in such a way as to reduce or eliminate the deformation of the first porous layer 2 and, if need be, the second porous layer 9.

Advantageously, the acid solution is hydrofluoric acid, or a buffer solution containing hydrofluoric acid.

Use of the chemical solution makes it possible to obtain desorption of the oxygen contained in the first porous layer and possibly in the second porous layer. The presence of oxygen in these layers is explained by the step of thermal oxidation carried out during the fourth step E4.

Use of the chemical solution makes it possible to obtain desorption of the surface layer created in the first and second porous layers. The first and second porous layers 2 and 9 can contain oxygen in one example embodiment if a thermal oxidation step was carried out during the fourth step E4.

In another example embodiment, the first and second porous layers 2 and 9 can contain silicon nitride because nitridation of the semiconductor device 15 will have been carried out during the fourth step E4.

The method is advantageously applied cyclically, and thus consists in cyclically applying the first, second, third, fourth, fifth and sixth steps, for the manufacture of a plurality of the receptor substrates 8 each comprising a strained useful layer 6' of a semiconductor material.

In all the embodiments of the sixth step, it should be noted that the novel layer 6, manufactured during a given iteration of the sixth step E6, can have a semiconductor material that is different than or identical to the semiconductor material of the layer 6 manufactured during a preceding iteration of the manufacturing method.

A second embodiment of the method for manufacturing a semiconductor receptor substrate of the invention is now described, in reference to Figure 6.

The method comprises a first step S1 consisting in forming a semiconductor support substrate 1 comprising a porous layer 2 of a semiconductor material. It is a layer 2 of a semiconductor material, which has been made porous. Examples of materials have already been cited in the first embodiment. Advantageously, all of support substrate 1 has been made porous, as illustrated in Figure 6.

Advantageously, layer 2 is made of silicon. Advantageously, all of substrate 1 is made of silicon.

This first step S1 is in general carried out by electrochemical anodization of the support substrate 1, whose principle was described above for step S1. The characteristics of this anodization will not be described again.

The method comprises a second step S2 consisting in providing a semiconductor donor substrate 4, comprising a useful layer 6 composed of semiconductor material.

The layer 6 is advantageously made of silicon.

The method comprises a third step S3 consisting in forming an oxide layer 7 in contact with the porous layer 2 and/or in contact with the useful layer 6.

In Figure 6, the case of an oxide layer 7 formed in contact with the porous layer 2 is illustrated.

The oxide layer is, for example but not limited to, SiO_2 .

The method comprises a fourth step S4 consisting of:

- bonding (step $S4_1$) the support substrate 1 and the donor substrate 4 at the oxide layer 7, and
- transferring (step $S4_2$) at least a portion of the layer 6 from the semiconductor material of the donor substrate 4 to the support substrate 1, to form a semiconductor device 15.

Before bonding, surfaces to be bonded together are generally cleaned.

The layer 6 composed of semiconductor material transferred from the donor substrate 4 to the support substrate 1 advantageously has a thickness between 10 nm and 1 μ m.

The transfer is carried out identically to the transfer described in the case of the step S3 described above, in the context of the first embodiment of the manufacturing method.

The characteristics of the third step S3 are transposed in the case of the fourth step S4, and will not be detailed again.

Thus, transfer of the layer 6 composed of semiconductor material from the donor substrate 4 to the support substrate 1 can comprise the use of a dismountable donor substrate 4.

Alternatively, the fourth step S4 of the transfer of the layer 6 composed of semiconductor material from the donor substrate 4 to the support substrate 1 advantageously comprises the steps of:

- creating an embrittlement zone 25 in the donor substrate 4, prior to bonding the support substrate 1 and the donor substrate 4,
- creating a fracture at said embrittlement zone 25, to detach the support substrate 1 from the donor substrate 4.

Alternatively, the transfer rests on the use of a confinement layer or a confinement structure, said transfer having been described above. It should be noted that the oxide layer (for example oxide layer 7) replaces the second porous layer 9 of the first embodiment. The characteristics of this transfer will thus not be detailed again, calling attention to the first embodiment.

In short, this transfer is carried out in the following manner (see Figure 7):

- the second step S2 comprises the supply of a donor substrate 4 further comprising a semiconductor confinement layer 30, said confinement layer possessing a different chemical composition than the useful layer, and

- the fourth step S4 consisting of transferring the useful layer 6 from the donor substrate 4 to the support substrate 1 comprises the following steps:
 - o introducing (step S401) the ions 24 into the donor substrate 4,
 - o bonding (step S402) the support substrate 1 and the donor substrate 4,
 - o subjecting (step S403) the support substrate 1 and the donor substrate 4 to heat treatment comprising an increase in temperature, during which the confinement layer 30 attracts the ions 24 to concentrate them in said confinement layer 30, and
 - o detaching (S404) the support substrate 1 from the donor substrate 4 by fracturing said confinement layer 30.

At the end of the fourth step S4, a semiconductor device 15 successively comprising a porous layer 2, an oxide layer 7 and part of the useful layer 6 is thus available.

By virtue of the invention, a thin layer of a semiconductor material transferred to a porous substrate is thus available, which is highly advantageous with respect to the difficulty obtaining thin layers of a semiconductor material on a porous substrate.

The remainder of the donor substrate 4 present on the support substrate 1 after fracturing can be removed by selective etching or any other method known to those persons skilled in the art.

A semiconductor device is thus obtained comprising successively:

- a first porous layer 2 composed of semiconductor material, and
- an oxide layer 7 in contact with the first porous layer 2, and
- a useful layer 6 composed of semiconductor material, which advantageously has a thickness between 10 nm and 1 μm .

By virtue of the invention, a thin layer of a semiconductor material transferred to a porous substrate is thus available, which is highly advantageous with respect to the difficulty obtaining thin layers of a

semiconductor material on a porous substrate, notably due to problems of adhesion of layers on a porous substrate.

The method comprises a fifth step S5 consisting of treating said semiconductor device 15 in such a way as to deform by dilation or contraction the porous layer 2 of the support substrate 1, said deformation inducing strain in the useful layer 6, then referred to as the strained useful layer 6'.

This fifth step S5 is carried out identically to the fourth step E4 described above in the context of the first embodiment of the manufacturing method, and will not be detailed again.

The method comprises a sixth step S6 of the transfer at least a portion of the strained useful layer 6' from the semiconductor device 15 to a receptor substrate 8, said transfer being configured to enable the partial or total preservation of the porous layer 2 of the support substrate 1. Total preservation is advantageous insofar as it enables total recycling of the porous layer 2.

The sixth step S6 can consist in:

- creating an embrittlement zone 40 in the semiconductor device 15, by ion implantation,
- bonding (step S6₁) the semiconductor device 15 and the receptor substrate 8, and
- creating (step S6₂) a fracture at said embrittlement zone 40, to detach the semiconductor device 15 from the receptor substrate 8, said transfer enabling the preservation of at least a portion of the porous layer 2 of the support substrate 1, or the totality of the porous layer 2.

Before bonding, the surfaces to be bonded together are generally cleaned.

The embrittlement zone is in general created by implantation of ions, such as hydrogen or helium ions.

If the embrittlement zone is created in the oxide layer 7, then the porous layer 2 is completely preserved. If the embrittlement zone is created in the porous layer 2, then the porous layer 2 is partially preserved.

The invention thus makes it possible to preserve the porous layer of the support substrate, which leaves the possibility of reusing this support substrate.

This makes it possible to implement a seventh step S7 of reuse of the support substrate, this step being able to cover various embodiments.

The seventh step S7 of reuse can comprise a step of treating the support substrate 1 with a chemical solution, in such a way as to reduce or eliminate the deformation of porous layer 2 of the support substrate 1. If the deformation results from oxidation of the porous layer 2, the seventh step thus consists of eliminating the oxide present in the porous layer 2. The elimination of this oxide is generally carried out via a treatment comprising a chemical solution, notably hydrofluoric acid, as already described above.

Alternatively, this step of reducing or eliminating the deformation of porous layer 2 of the support substrate 1 is not carried out. Indeed, this step is not always necessary, and the support substrate 1 can then be reused directly in one or more of the steps of the method.

It should be noted that the implementation of this step makes it possible to increase the number of recycling cycles. Indeed, the greater the strain in the porous layer 2 (due to high oxidation of the porous layer 2, for example), the slower the oxidation implemented in step S5 (repeated during recycling) to strain the useful layer 6. If oxidation of the porous layer 2 is high, it is, for example, possible to treat the support substrate 1 with a hydrofluoric acid solution to eliminate this oxide, and thus to increase the oxidation rate in step S5 which is repeated during recycling.

The support substrate 1 can be reused during one or more of the steps of the method.

It is not always necessary to recreate an oxide layer in contact with the porous layer 2 (third step), since at the end of the sixth step an oxide layer in contact with the porous layer 2 can remain.

Thus, the method advantageously comprises a seventh step S7 consisting in reusing the support substrate 1 comprising the porous layer, at least in:

- the second step S2 (supply of a semiconductor donor substrate 4, comprising a useful layer 6 composed of semiconductor material), and
- the fourth step S4 (transfer of the useful layer for the manufacture of a novel semiconductor device 15).

In one embodiment, the seventh step S7 consists in reusing the support substrate 1 comprising the porous layer, at least in:

- the second step S2 (supply of a semiconductor donor substrate 4, comprising a useful layer 6 composed of semiconductor material),
- the third step S3 (formation of an oxide layer in contact with the porous layer 2 and/or in contact with the useful layer 6), and
- the fourth step S4 (transfer of the useful layer for the manufacture of a novel semiconductor device 15).

In another embodiment, the seventh step S7 consists in reusing the support substrate 1 comprising the porous layer 2, at least in:

- the second and fourth steps S2 and S4 (with optionally the third step S3 of recreating an oxide layer), and
- the fifth step S5 (treatment of the semiconductor device in such a way as to deform the porous layer by dilation or contraction, said deformation inducing strain in the useful layer, then referred to as the strained useful layer), for the manufacture of a novel semiconductor device 15.

In yet another embodiment, the seventh step S7 consists in reusing the support substrate 1 comprising the porous layer 2, at least in:

- the second, fourth and fifth steps (with optionally repetition of the third step of creating an oxide layer), and
- the sixth step S6 of the manufacturing method (step of transferring the semiconductor device 15 to a receptor substrate 8), for the manufacture of a novel receptor substrate 8.

This embodiment makes it possible to preserve the porous layer of the support substrate 1, and to obtain a semiconductor device comprising a thin layer of a semiconductor material in contact with said porous layer.

An additional method for manufacturing and recycling semiconductor substrates will now be described, in reference to Figure 8.

The method comprises a first step P1 consisting in providing a semiconductor donor substrate 39 comprising at least one porous layer 31 composed of a first semiconductor material and a strained layer 32 composed of a second semiconductor material.

The first and second materials can be identical or different. "Different" means that these materials have different lattice parameters in the relaxed state.

As an example, the first and second materials are silicon or germanium or a group III-V alloy.

The donor substrate 39 can, for example, be supplied according to the following steps.

A substrate comprising a first layer composed of a first semiconductor material and a second layer composed of a second semiconductor material is subjected to selective chemical anodization.

For example, current density is varied to make only the first layer porous. Alternatively, or complementarily, the first layer is doped p, while the second layer is doped n, which makes it possible to make the substrate porous selectively, *i.e.*, to make only the first layer porous.

It is possible to vary the parameters of the anodization process to obtain the pore characteristics desired, such as porosity, pore size, pore morphology, pore density, crystallite size, etc.

Anodization parameters include substrate doping type and level, crystalline orientation of the layer material, current density, electrolyte composition and concentration, temperature and anodization time.

The straining of layer 32 can notably be obtained by deforming by expansion or contraction the porous layer 31, according to the embodiments described above, such as, for example, thermal oxidation or nitridation of the donor substrate 39. This deformation induces strain in layer 32.

The method comprises a second step P2 consisting of creating an embrittlement zone 33 in the semiconductor donor substrate 39, by ion implantation 34.

Ion implantation can be carried out in the porous layer 31, or the strained layer 32, or in other intermediate layers if the semiconductor donor substrate 39 comprises additional layers.

The ions are, for example, selected from hydrogen ions, helium ions or boron ions, or a combination of hydrogen with the latter two ions.

The method comprises a third step P3 consisting in bonding the semiconductor donor substrate 39 with a receptor substrate 36. The receptor substrate 36 is, for example, a semiconductor substrate comprising an oxide layer.

In general, the surfaces to be bonded together are cleaned beforehand, to facilitate bonding.

Advantageously, an oxide layer is formed on the surface of the receptor substrate 36 and/or the donor substrate 30, to promote bonding. In Figure 5, it is the receptor substrate 36 which comprises the oxide layer 40, but it can comprise other layers, such as a semiconductor layer 35.

The method comprises a fourth step P4 consisting of creating a fracture at the embrittlement zone 33.

The fracture is in general obtained by increasing temperature. In particular, the temperature will be increased to between 200 °C and 700 °C.

The receptor substrate 36 comprising at least a portion of the strained layer 32 of the second semiconductor material, and the donor substrate 30, comprising at least a portion of the porous layer 31, are thus obtained.

Thus, the porous layer 31 is preserved, partly or entirely, which makes it possible to reuse the donor substrate 39.

Advantageously, the embrittlement zone is selected in such a way as to completely preserve the porous layer 31 of the donor substrate 30 (which amounts in practice to creating the embrittlement zone and the fracture in a layer located outside the porous layer 31).

If the second semiconductor material is silicon, the receptor substrate 36 obtained at the end of the fourth step P4 is a strained silicon on insulator (sSOI) substrate.

The receptor substrate 36 then undergoes a finishing treatment, including in general polishing, with a view to the use thereof in electronic devices.

The method advantageously comprises a fifth step P5 of recycling consisting in reusing the donor substrate 39, comprising at least a portion of the porous layer 31, for the manufacture of a novel receptor substrate 36 comprising a strained layer 32 of the second semiconductor material, or of another semiconductor material.

This recycling step P5 comprises in general treatment of the donor substrate 30 to reduce defects and roughness of the donor substrate 30 appearing after the fracture procedure.

This advantageously involves removal of the corona 38 present on the edges of the donor substrate 30 and resulting from the fracture procedure.

This step is, for example, implemented by rapid double-sided polishing or selective chemical or chemical-mechanical etching and/or edge trimming.

It is followed in general by polishing, for example chemical-mechanical polishing (CMP), to reduce or smooth surface roughness.

The recycling step P5 advantageously comprises the repetition of the first, second, third and fourth steps for the manufacture of a novel receptor substrate 36 comprising a strained layer 32 of the second semiconductor material, or another semiconductor material.

During the repetition of the first step, an advantageous embodiment comprises the following steps:

- a layer 32 of the second semiconductor material or of another semiconductor material is formed in contact with the porous layer 31 of the donor substrate 39, and

- the porous layer 31 is then deformed by expansion or contraction to apply strain to layer 32.

This deformation can, for example, be carried out by thermal oxidation of the donor substrate 30, or nitridation, as already described above and in the preceding embodiments.

It is advantageous that the porous layer 31, provided in the first iteration of the manufacturing method, has a thickness greater than 100 μm in order to enable successive deformation operations during the recycling steps (oxidation, nitridation, etc.).

In certain cases, the recycling step P5 advantageously comprises the repetition of the second, third and fourth steps for the manufacture of a novel receptor substrate 36 comprising a strained layer 32 of the second semiconductor material. Indeed, in certain cases, the strained layer 32 will have been only partly transferred to the preceding iteration. Thus, during recycling, it is not necessary to recreate one such strained layer 32, and it is possible to transfer part or all of this layer 32 by starting again from the second step.

It is possible that the recycling step P5 comprises a preliminary step of treating the donor substrate 30 with a chemical solution to reduce or eliminate deformation of the porous layer 31. Indeed, as explained above, use of the chemical solution makes it possible to obtain desorption of the surface layer created in the porous layer 31. The porous layer 31 can notably contain oxygen in an example embodiment if a thermal oxidation step has been carried out on the donor substrate 30, or can contain silicon nitride if nitridation has been carried out.

The method can be applied cyclically, by repeating the desired steps in a cyclic manner.

The invention has many advantages in terms of reducing costs, reducing manufacturing lead times and obtaining strained useful layers of good quality.

CLAIMS

1. A method for manufacturing a semiconductor device, characterized in that it comprises:

- a first step (E1) consisting in forming a semiconductor support substrate (1) comprising:
 - o a first porous layer (2) consisting of semiconductor material, and
 - o a second porous layer (9) consisting of semiconductor material, with a porosity lower than the porosity of the first layer (2),
- a second step (E2) consisting in providing a semiconductor donor substrate (4), comprising a useful layer (6) composed of semiconductor material,
- a third step (E3) consisting of:
 - o bonding the support substrate (1) and the donor substrate (4),
 - o transferring at least a portion of the useful layer (6) from the donor substrate (4) to the support substrate (1), to form a semiconductor device (15), and
- a fourth step (E4) consisting of treating said semiconductor device (15) in such a way as to deform by dilation or contraction at least the first porous layer of the support substrate (1), said deformation inducing strain in the useful layer (6), then referred to as the strained useful layer (6').

2. The method of claim 1, wherein the useful layer (6) transferred from the donor substrate (4) to the support substrate (1) has a thickness between 10 nm and 1 μ m.

3. The method of any one of claims 1 or 2, wherein the third step (E3) of transferring the useful layer (6) from the donor substrate (4) to the support substrate (1) comprises the steps of:

- creating an embrittlement zone (25) in the donor substrate (4), prior to bonding the support substrate (1) and the donor substrate (4), by ion implantation,
 - creating a fracture at said embrittlement zone (25) to detach the support substrate (1) from the donor substrate (4).
4. The method of claim 1 or claim 2, wherein the transfer of the useful layer (6) from the donor substrate (4) to the support substrate (1) comprises the use of a dismountable donor substrate (4).
5. The method of claim 1 or claim 2, wherein:
- the second step (E2) comprises the supply of a donor substrate (4) further comprising a semiconductor confinement layer (30), said confinement layer (30) having a different chemical composition than the useful layer (6), and
 - the third step (E3) consisting of transferring the useful layer (6) from the donor substrate (4) to the support substrate (1) comprises the following steps:
 - introducing (E301) ions (24) into the donor substrate (1),
 - bonding (E302) the support substrate (1) and the donor substrate (4),
 - subjecting (E303) the support substrate (1) and the donor substrate (4) to heat treatment comprising an increase in temperature, during which the confinement layer (30) attracts ions (24) and concentrates them within said confinement layer (30), and
 - detaching (E304) the support substrate (1) from the donor substrate (4) by fracturing said confinement layer (30).
6. The method of claim 1, in combination with one of claims 2 to 5, comprising:

- a fifth step (E5) consisting of transferring at least a portion of the strained useful layer (6') of the semiconductor device (15) to a receptor substrate (8), and
- a sixth step (E6) consisting in reusing the support substrate (1),
 - o at least in the second and third steps of the manufacturing method, for the manufacture of a novel semiconductor device (15), or
 - o at least in the second, third and fourth steps of the manufacturing method, for the manufacture of a novel semiconductor device (15), or
 - o at least in the second, third, fourth and fifth steps of the manufacturing method, for the manufacture of a new receptor substrate (8).

7. A method for manufacturing a semiconductor receptor substrate, characterized in that it comprises:

- a first step (S1) consisting in forming a semiconductor support substrate (1) comprising a porous layer (2) consisting of semiconductor material,
- a second step (S2) consisting in providing a semiconductor donor substrate (4), comprising a useful layer (6) composed of semiconductor material,
- a third step (S3) consisting in forming an oxide layer (7) in contact with the porous layer (2) and/or in contact with the useful layer (6),
- a fourth step (S4) consisting of:
 - o bonding the support substrate (1) and the donor substrate (4) at the oxide layer (7), and
 - o transferring at least a portion of the useful layer (6) from the donor substrate (4) to the support substrate (1), to form a semiconductor device (15),
- a fifth step (S5) consisting of treating said semiconductor device (15) in such a way as to deform by dilation or contraction the porous layer

- (2), said deformation inducing strain in the useful layer (6), then referred to as the strained useful layer (6'),
- a sixth step (S6) consisting of transferring at least a portion of the strained useful layer (6') of the semiconductor device (15) to a receptor substrate (8), said transfer being configured to enable the partial or total preservation of the porous layer (2) of the support substrate (1).
8. The method of claim 7, wherein the sixth step (S6) consists of:
- creating an embrittlement zone (40) in the semiconductor device (15),
 - bonding the semiconductor device (15) and the receptor substrate (8), and
 - creating a fracture at said embrittlement zone (40) to detach the semiconductor device (15) from the receptor substrate (8).
9. The method of claim 7 or claim 8, wherein the useful layer (6) transferred from the donor substrate (4) to the support substrate (1) has a thickness between 10 nm and 1 μ m.
10. The method of any one of claims 7 to 9, wherein the fourth step (S4) of transferring the useful layer (6) from the donor substrate (4) to the support substrate (1) comprises the steps of:
- creating an embrittlement zone (25) in the donor substrate (4), prior to bonding the support substrate (1) and the receptor substrate (4), by ion implantation,
 - creating a fracture at said embrittlement zone (25) to detach the support substrate (1) from the receptor substrate (4).
11. The method of any one of claims 7 to 10, wherein the transfer (S4) of the strained useful layer (6') of the donor substrate (4) to the support substrate (1) comprises the use of a dismountable donor substrate (4).

12. The method of any one of claims 7 to 11, wherein:
- the second step (S2) comprises the supply of a donor substrate (4) further comprising a semiconductor confinement layer (30), said confinement layer (30) having a different chemical composition than the useful layer (6), and
 - the fourth step (S4) consisting of transferring the useful layer (6) from the donor substrate (4) to the support substrate (1) comprises the following steps:
 - o introducing (S401) ions (24) into the donor substrate (4),
 - o bonding (S402) the support substrate (1) and the donor substrate (4),
 - o subjecting (S403) the support substrate (1) and the donor substrate (4) to heat treatment comprising an increase in temperature, during which the confinement layer (30) attracts ions (24) and concentrates them within said confinement layer (30), and
 - o detaching (S404) the support substrate (1) from the donor substrate (4) by fracturing said confinement layer (30).
13. The method of one of claims 7 to 12, comprising a seventh step (S7) consisting in reusing the support substrate (1) comprising the porous layer,
- at least in the second and fourth steps of the manufacturing method, for the manufacture of a novel semiconductor device (15), or
 - at least in the second, fourth and fifth steps of the manufacturing method, for the manufacture of a novel semiconductor device (15), or
 - at least in the second, fourth, fifth, and sixth steps of the manufacturing method, for the manufacture of a novel receptor substrate (8).
14. A semiconductor device comprising successively:
- a first porous layer (2) composed of semiconductor material,

- a second porous layer (9) composed of semiconductor material, and with a porosity lower than the porosity of the first layer (2), and
 - a strained useful layer (6') composed of semiconductor material, with a thickness between 10 nm and 1 μm .
15. A semiconductor device comprising successively:
- a first porous layer (2) composed of semiconductor material,
 - an oxide layer (7) in contact with the first porous layer (2), and
 - a strained useful layer (6') composed of semiconductor material, with a thickness between 10 nm and 1 μm .

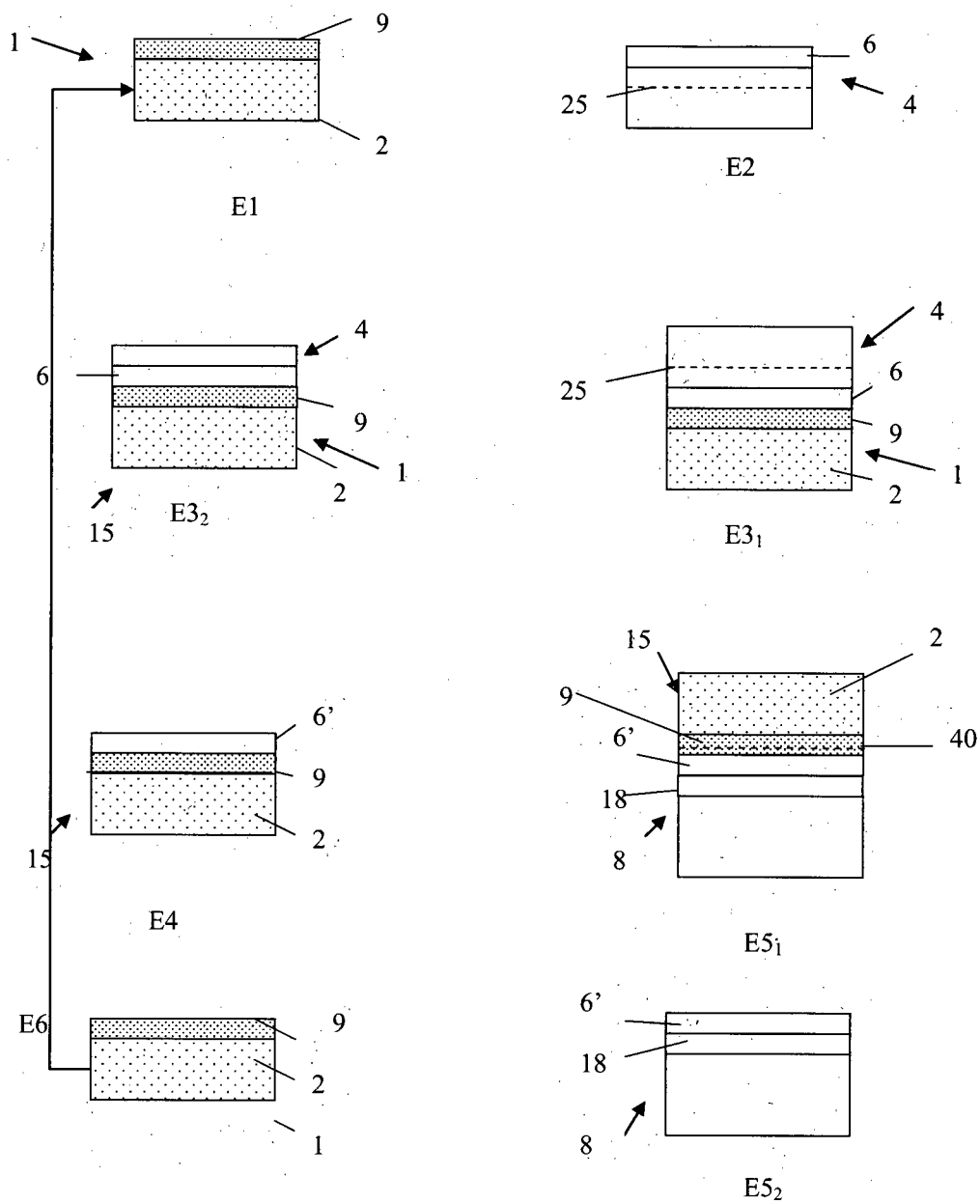


Figure 1

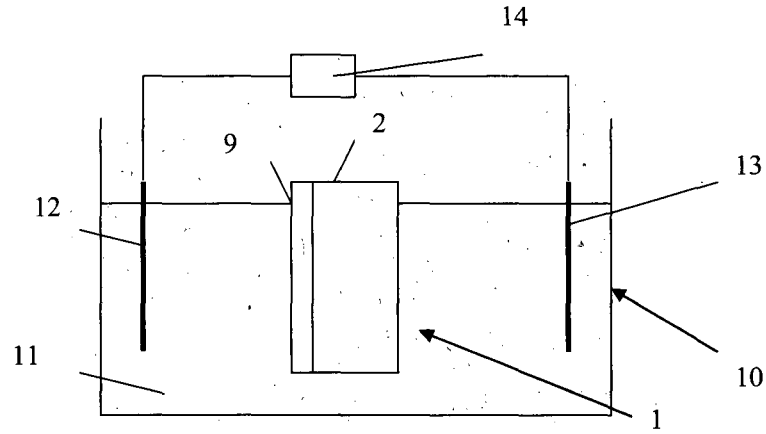


Figure 2

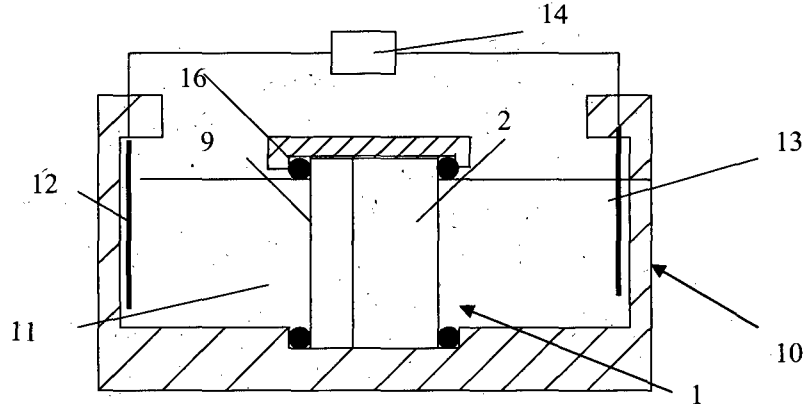


Figure 3

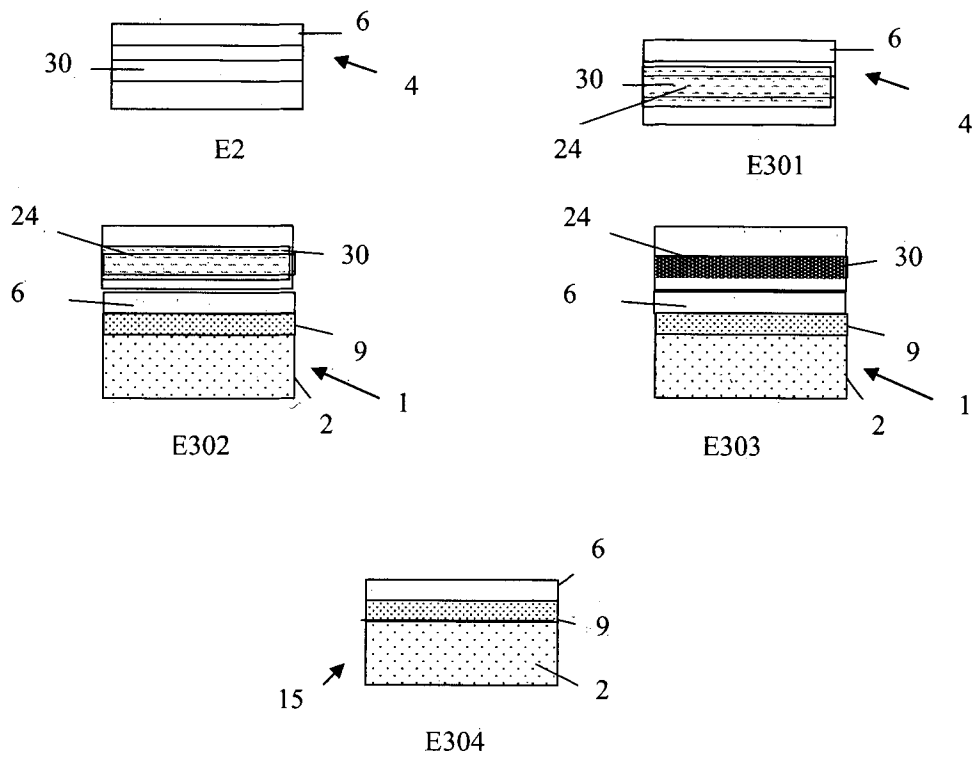


Figure 4

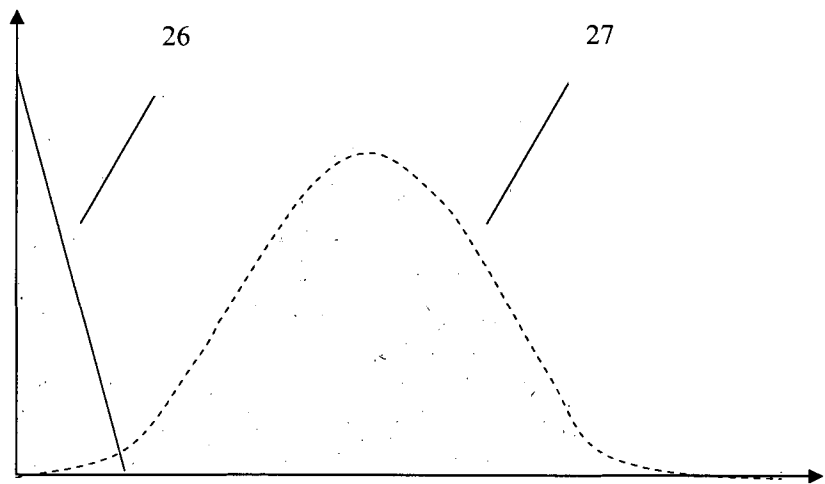


Figure 5

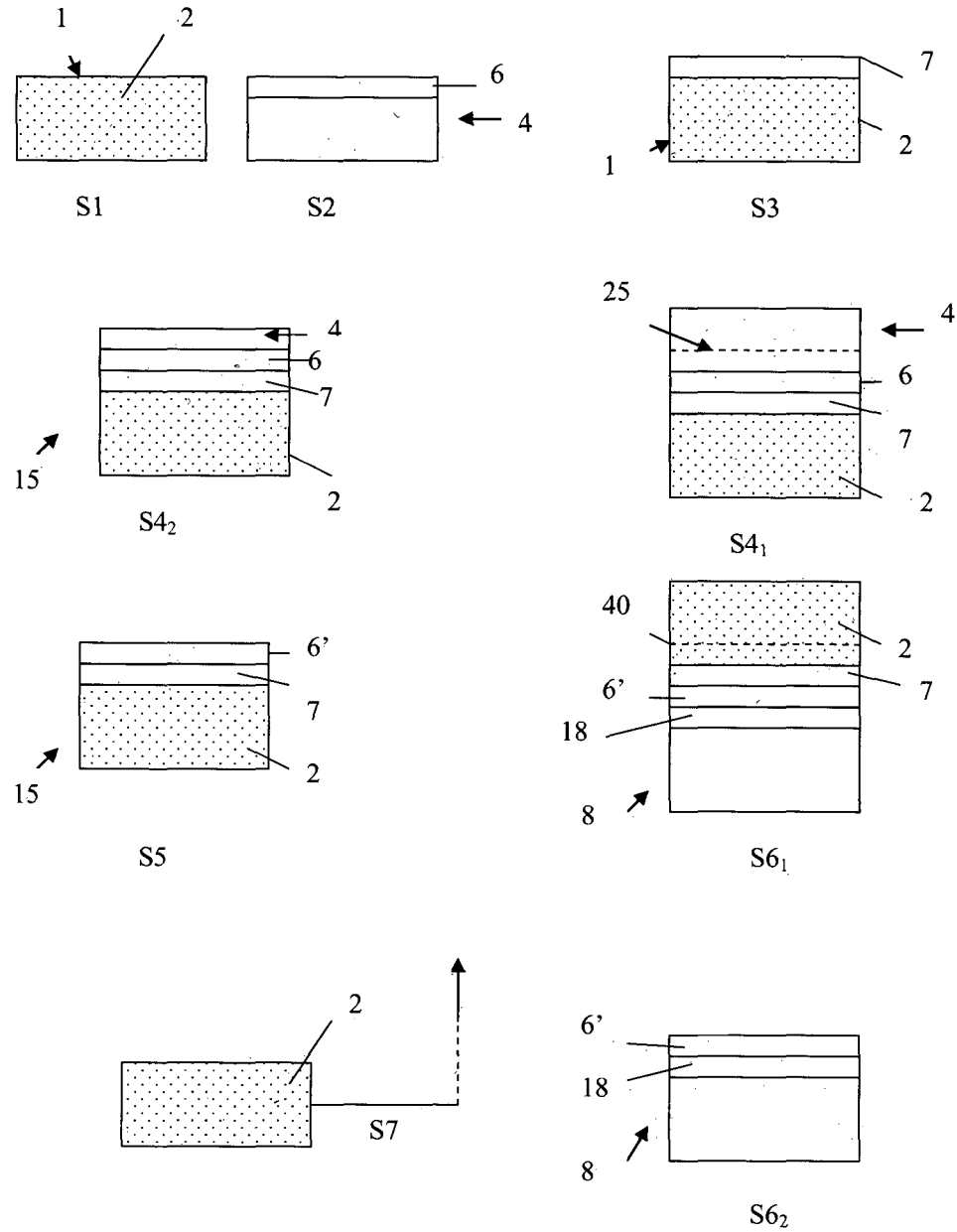


Figure 6

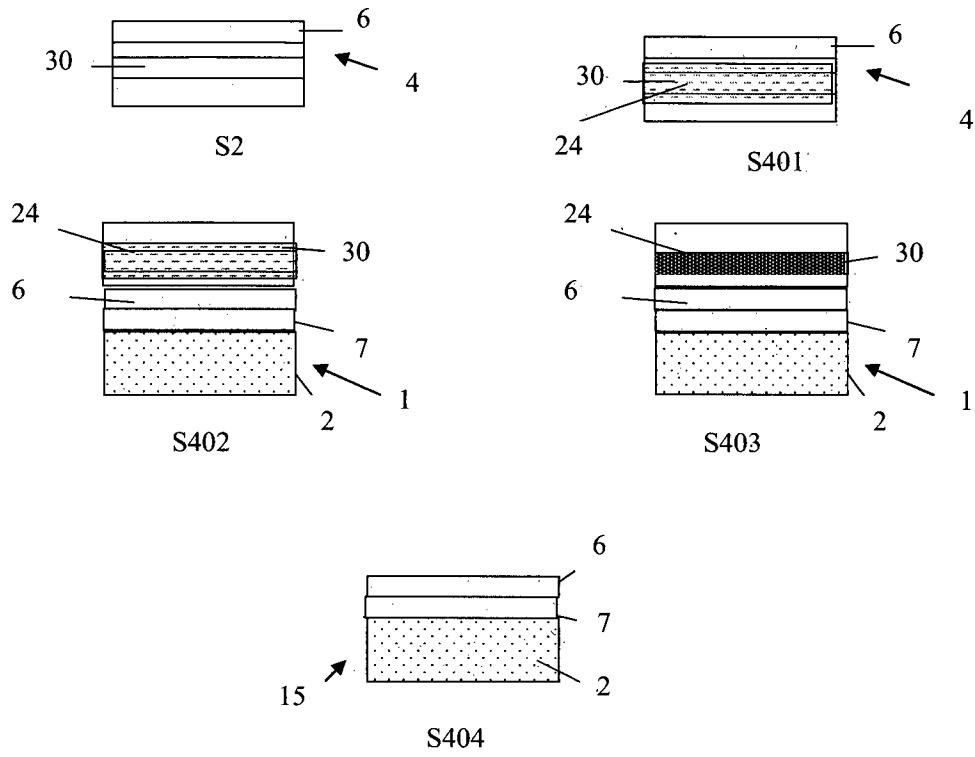


Figure 7

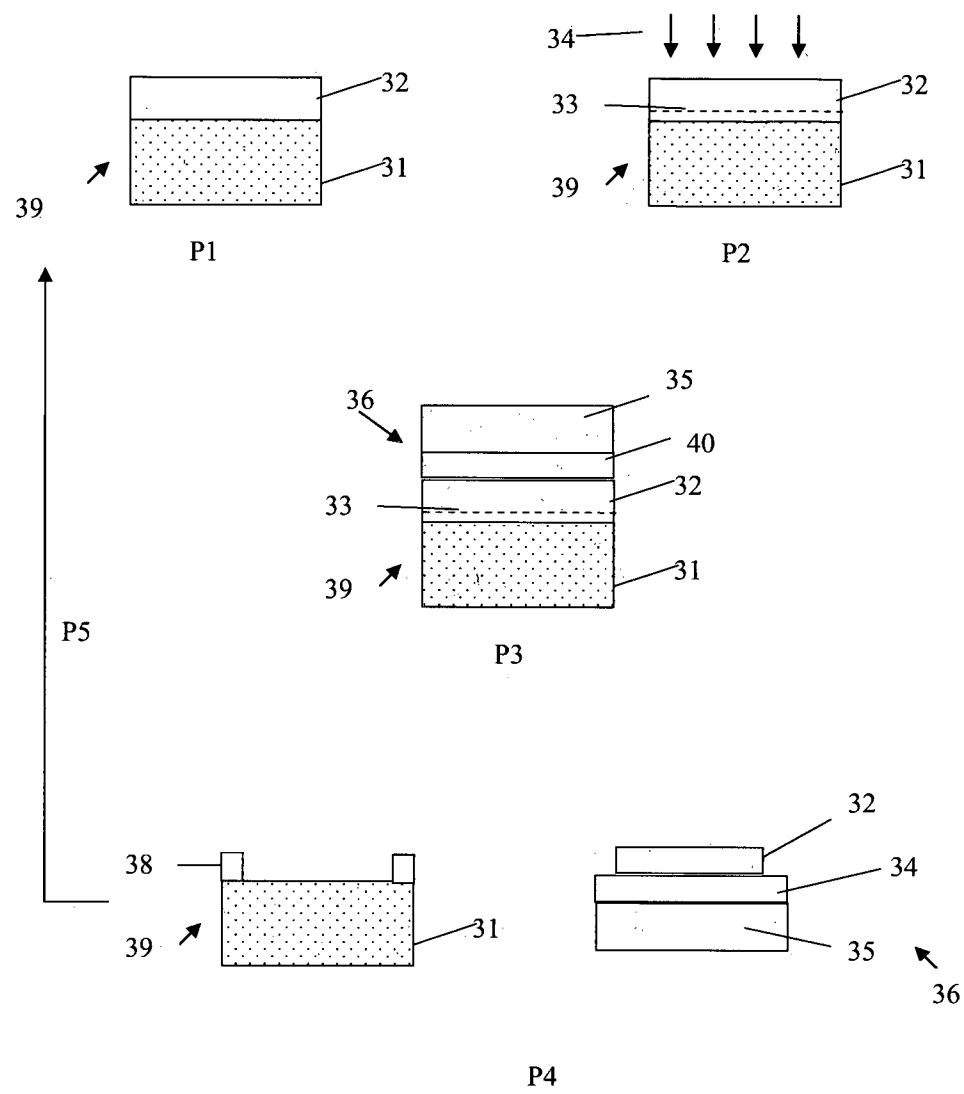


Figure 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2012/001125

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L21/762
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2005/064658 A1 (CANON KK [JP]; NOTSU KAZUYA [JP]; SAKAGUCHI KIYOFUMI [JP]; SATO NOBUHI) 14 July 2005 (2005-07-14) paragraph [0081] - paragraph [0104]; figures 1-8 paragraph [0117] - paragraph [0130] -----	1-15
X	JP 2005 191458 A (CANON KK) 14 July 2005 (2005-07-14) paragraph [0023] - paragraph [0050]; figures 1-7 -----	1-15
X	EP 1 039 513 A2 (CANON KK [JP]) 27 September 2000 (2000-09-27) paragraph [0285] - paragraph [0293]; figure 13 ----- -/-	7-13

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2012/001125

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

International application No

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