

PROCESS FOR OBTAINING A THIN LAYER OF INCREASED QUALITY
BY CO-IMPLANTATION AND THERMAL ANNEALING

The present invention relates to a process for producing a structure comprising a thin layer of semiconductor material on a substrate, comprising the following stages:

- 5 • carrying out implantation of species under a face of a donor substrate from which the thin layer must be made, so as to create an embrittlement zone in the thickness of the donor substrate,
- placing the face of the donor substrate in close
10 contact with a support substrate after it has undergone implantation,
- detaching the donor substrate at the embrittlement zone, to transfer a part of the donor substrate onto the support substrate and form the thin layer on the
15 latter.

And the invention also concerns structures obtained by using such a process.

Implantation of species is understood to mean any bombardment of atomic or ionic species, likely to
20 introduce these species onto the material of the

implanted substrate, with a maximum concentration of the implanted species situated at a preset depth from the substrate relative to the bombarded surface.

Processes of the type mentioned hereinabove are
5 already known.

The processes of SMARTCUT® type are an example of a process of this type. These processes correspond to a preferred embodiment of the invention.

More ample details concerning the SMARTCUT® process
10 are to be found in the document 'Silicon-On-Insulator Technology: Materials to VLSI, 2nd Edition', by Jean-Pierre Colinge from Kluwer Academic Publishers, pp. 50 and 51.

Such processes advantageously produce structures
15 comprising a thin layer of semiconductor material.

These structures can be of SOI type (Silicon On Insulator, for Silicon sur Isolant, according to widely-accepted English terminology).

The resulting structures from such processes are
20 used for applications in the field of microelectronics, optics and/or optronics.

Now, the specifications of the surface state of the structures used in these fields are generally very strict.

25 The roughness of the thin layer is in effect a parameter which to a certain extent conditions the quality of the components which will be created on the structure.

The roughness is generally expressed either by an
30 average quadratic value known as RMS (Root Mean Square according to the English acronym), or by a spectral

power density known as PSD (Power Spectral Density according to the English acronym).

By way of example, it is current to find roughness specifications which must not exceed 5 Angströms in
5 RMS value.

The roughness measures can be done by means of an atomic force microscope AFM (Atomic Force Microscope, according to the English acronym).

With this type of instrument, the roughness is
10 measured on surfaces swept by the point of the AFM microscope, ranging from $1 \times 1 \mu\text{m}^2$ to $10 \times 10 \mu\text{m}^2$, and more rarely $50 \times 50 \mu\text{m}^2$, or $100 \times 100 \mu\text{m}^2$.

The roughness can be characterised, in particular, according to two modalities.

15 According to one of these modalities, the roughness is said to be high frequency and corresponds to small-sized swept surfaces (of the order of $1 \times 1 \mu\text{m}^2$),

According to the other of these modalities, the roughness is said to be low frequency and corresponds
20 to swept surfaces larger in size (of the order of $10 \times 10 \mu\text{m}^2$, or more).

The abovementioned "high frequencies" and "low frequencies" correspond therefore to spatial frequencies associated with the roughness measuring.

25 The specification of 5 Angströms RMS given hereinabove by way of indicative example is therefore a low-frequencies roughness, corresponding to a swept surface of $10 \times 10 \mu\text{m}^2$.

Low roughness at high frequencies is in particular
30 desired to obtain good gate oxides.

Low roughness at low frequencies (or waviness) is of interest particularly when the aim is to bond another substrate onto the free surface of the thin layer.

The thin layers which are obtained by the known transfer processes (for example of SMARTCUT® type) have surface roughnesses with values generally greater than specifications such as mentioned hereinabove, in the absence of application to the surface of the thin layer of a specific treatment.

Finishing steps are therefore generally utilised on the structure following the detachment stage, so as to improve the quality of the thin transferred layer.

More precisely, it is especially an object of these finishing steps to gum out all the roughnesses, that is, including both the high-frequencies roughnesses and the low-frequencies roughnesses.

These finishing steps generally make use of operations such as chemical-mechanical polishing (or CMP according to the English term Chemical-Mechanical Polishing), kiln annealing, rapid annealing, oxidation/deoxidation sequence.

A first type of known process for decreasing surface roughness comprises chemical-mechanical polishing the free surface of the thin layer.

This type of process effectively reduces the roughness of the free surface of the thin layer by decreasing all waviness, and especially those at the lowest frequencies.

However, chemical-mechanical polishing causes defects (for example by cold working) in the thin layer.

In addition, it compromises the uniformity of the free surface of the thin layer (in particular uniformity according to the very low frequencies).

These disadvantages are further augmented in the case where the surface of the thin layer is polished in an important way.

As an alternative to such CMP polishing, it has been proposed to treat the surface of the structure by annealing in hydrogenated atmosphere.

10 The document EP 954 014 proposes a finishing process enabling the roughness of a thin layer, transferred according to a SMARTCUT® type process, to be decreased, said finishing process comprising, following the detachment step, a thermal annealing in reducing
15 atmosphere containing hydrogen.

Thermal annealing in reducing atmosphere containing hydrogen enables gumming out the high-frequencies roughnesses by surface reconstruction.

But this treatment does not allow total elimination
20 of the lowest-frequencies roughnesses (5 to 10 micrometers).

It has further been proposed in FR 2 797 713 to combine two different types of surface treatment, each of these two types of treatment acting on distinct
25 roughness frequency ranges.

A step of rapid thermal annealing in reducing atmosphere as well as a step of chemical-mechanical polishing (CMP) are thus carried out, said steps being distinguished by their effects on different frequency
30 ranges.

In the case of such treatment, annealing in reducing atmosphere benefits smoothing the high-

frequencies roughnesses (spatial period of less than 3 Angströms), but is less efficient for reducing waviness, which are more of low frequency.

The chemical-mechanical polishing is efficacious
5 per se for decreasing the low-frequency waviness.

But as it has already been seen, chemical-mechanical polishing is intrinsically associated with certain disadvantages.

It therefore appears that the processes known for
10 improving the quality of the thin layer of a structure of the abovementioned type are associated with limitations or drawbacks.

An aim of the invention is to effectively eliminate these limitations and disadvantages.

15 More specifically, another aim of the invention is to enable effective treatment of roughness, both low-frequency and high-frequency, of structures, without recourse to CMP type polishing.

An aim of the invention is therefore to improve the
20 quality of the thin superficial layer, where improvement of the quality is understood as:

- decrease of the surface roughness and improvement in the uniformity of the thin layer, as well as
- reduction in the density of defects present in the
25 thin layer.

To achieve these aims, the invention proposes, according to a first aspect, a process for producing a structure comprising a thin layer of semiconductor material on a substrate, comprising the following
30 stages:

- implantation of species, under a face of a donor substrate, from which the thin layer must be made, so

as to create an embrittlement zone in the thickness of the donor substrate;

- placing the face of the donor substrate in close contact with a support substrate, after it has undergone implantation;
- detaching the donor substrate at the embrittlement zone, for transferring a part of the donor substrate onto the support substrate and forming the thin layer on the latter;

characterised in that:

- the implantation step implements a co-implantation of at least two different atomic species so as to minimise the low-frequencies roughnesses at the level of the structure obtained after detachment;
- and the process further comprises a finishing step comprising at least one rapid thermal annealing operation so as to minimise the high-frequencies roughnesses at the level of the structure obtained after detachment.

Preferred aspects, though non-limiting aspects, of the process according to the first aspect of the invention are as follows:

- the hydrogen and helium species are co-implanted during said implantation stage;
- said hydrogen and helium species are implanted sequentially;
- the helium is implanted prior to the hydrogen;
- the dose of implanted helium is substantially between $0.7 \cdot 10^{16} \cdot \text{cm}^{-2}$ and $1.2 \cdot 10^{16} \cdot \text{cm}^{-2}$ and the dose of implanted hydrogen is substantially between $0.7 \cdot 10^{16} \cdot \text{cm}^{-2}$ and $2 \cdot 10^{16} \cdot \text{cm}^{-2}$;

- the rapid thermal annealing (RTA) is carried out at a temperature of between 900°C and 1300°C during 1 to 60 seconds;
- 5 • the RTA annealing is carried out in an atmosphere comprising a mixture of hydrogen and argon, or in an atmosphere of pure argon, or in an atmosphere of pure hydrogen;
- 10 • said finishing stage can also comprise at least one operation of stabilised oxidation StabOx of the structure obtained after detachment;
- said StabOx operation successively implements an oxidation operation, an annealing operation and a deoxidation operation;
- 15 • said annealing operation is carried out during two hours at a temperature of around 1100°C;
- during the finishing step, the RTA annealing operation can be carried out prior to the StabOx operation;
- 20 • said finishing step can comprise a plurality of RTA/StabOx sequences;
- during the finishing step, the StabOx operation can likewise be carried out prior to the RTA annealing operation;
- 25 • said finishing step can comprise a plurality of StabOx/RTA sequences;
- 30 • the StabOx operation(s) can be replaced by a simple oxidation operation, said simple oxidation operation comprising an oxidation operation of the structure obtained after detachment followed by a deoxidation operation.

In accordance with another aspect, the invention also relates to the structures created by implementing the process according to the first aspect of the invention.

5 Other characteristics, aims and advantages of the invention will emerge from the following detailed description, and with respect to the attached figures, given by way of non-limiting examples, in which:

10 • Figure 1 shows PSD-type roughnesses measurements made in the centre of various structures, and illustrates the reduction in low-frequencies roughnesses which can be carried out by utilising the process according to the present invention, relative to that which is obtained by simple thermal treatment of the RTA type;

15 • Figure 2 shows RMS roughness measurements and illustrates the reduction in low-frequencies roughnesses which can be carried out by the process according to the present invention, and this without recourse to a CMP step;

20 • Figures 3a and 3b are similar representations analogues to that in Figure 1, and illustrate the reduction in roughness obtained by the invention, respectively at the centre of a structure and at the edge of the same structure.

25 As it has already been explained, the invention relates to the production of structures comprising a thin layer of semiconductor material on a support substrate, the thin layer being obtained by detachment at the level of a donor substrate previously embrittled
30 by implantation of species.

The structure can, in general, be any type of structure comprising a thin layer of a semiconductor

material on a surface exposed to the external environment (free surface).

In a non restriction way, the thin layer of semiconductor material can be silicon Si, silicon
5 carbide SiC, germanium Ge, silicon-germanium SiGe, gallium arsenic AsGa, etc.

The substrate support can be made of silicon Si, quartz, etc.

A layer of oxide can also be intercalated in
10 between the support substrate and the thin layer, the structure therefore formed being a semiconductor-on-insulator structure (a SeOI structure according to the English acronym Semi-Conductor-On Insulator), and in particular a SOI structure, for example).

15 The invention can aid in improving the quality of the thin layer of a structure obtained by utilising a transfer process of the SMARTCUT® type.

Within the scope of such a transfer process, the invention could be implemented beneficially to
20 decrease the roughness of one or the other of the two surfaces of semiconductor material originating from detachment at the level of the embrittlement zone, or from these two surfaces.

Within the scope of the process according to the
25 present invention:

- the implantation step of species with the aim of creating an embrittlement zone is carried out by co-implantation of at least two different species under a face of the donor substrate,
- 30 • also, after detachment at the embrittlement zone, a finishing step by rapid thermal annealing is implemented.

In accordance with an embodiment of the invention, the hydrogen and helium species are co-implanted under the face of the donor substrate in order to form the embrittlement zone.

5 Preferably, though not exclusively, co-implantation is carried out by sequentially implanting helium then hydrogen.

By experimenting with co-implantation, the applicant has observed that the co-implantation of
10 helium and hydrogen resulted in transfer of the thin layers with a reduced level of roughness relative to the transfer following implantation of hydrogen alone.

More precisely, the applicant has observed that the frequencies at which this improvement in roughness seems
15 the most pronounced correspond to the frequencies of the lowest spatial frequency roughness, that is, the frequencies generally well treated by the CMP.

Within the scope of the process according to the present invention, the face of the donor substrate which
20 has undergone co-implantation is then placed in close contact with the support substrate.

The donor substrate is then detached at the level of the embrittlement zone, for transferring a part of the donor substrate to the support substrate and form
25 the thin layer on the latter.

These stages of close contact and detachment are known to the expert and are used conventionally in the transfer processes mentioned above.

Detachment can therefore be carried out by thermal
30 power supply, optionally by a mechanical action at the level of the embrittlement zone.

The process according to the invention also comprises a finishing step, whereof the object is especially to minimise the high-frequencies roughnesses at the level of the structure obtained after
5 detachment.

Such a finishing step comprises at least one stage of rapid thermal annealing.

Rapid thermal annealing is understood to mean rapid annealing, (that is, performed over a period of several
10 seconds or several tens of seconds), in a controlled atmosphere.

Such annealing is commonly designated by the term RTA annealing (corresponding to the English acronym Rapid Thermal Annealing).

15 To carry out RTA annealing of the structure, the structure is annealed at a high temperature, which can be for example of the order of 900°C to 1300°C, for 1 to 60 seconds.

RTA annealing is carried out in a controlled
20 atmosphere. This atmosphere can be an atmosphere comprising a mixture of hydrogen and argon, or an atmosphere of pure argon, or even an atmosphere of pure hydrogen.

The RTA annealing stage in particular reduces the
25 surface roughness of the thin layer, essentially by surface reconstruction and smoothing.

And, as mentioned earlier, RTA annealing especially benefits reduction of the roughness at high frequencies.

In addition, the crystalline defects present in the
30 thin layer, and generated in particular during implantation and detachment, are at least in part cured by this RTA annealing.

The process according to the present invention to obtain a structure with a thin layer of good quality does not therefore utilise CMP, though it does reduce both the high-frequencies roughnesses, as well as the
5 low-frequencies roughnesses.

Implementing the process according to the present invention thus results in a structure comprising a thin layer whereof the quality is adequate and compatible with using this thin layer in micro- or optoelectronic
10 applications.

According to a variant embodiment, said finishing stage can also comprise at least one stabilised oxidation step (likewise referred to as StabOx hereinbelow).

15 A StabOx step is classically used in a transfer process, following the detachment stage, particularly for:

- regulating the thickness of the thin layer and reducing the density of defects;
- 20 • reinforcing the interface between the thin layer and the support substrate.

Consequently, a StabOx stage will be similar to the succession of following operations:

- thermal treatment comprising successively:
 - 25 > oxidation of the structure.
 - ✓ such oxidation, classically known to the expert, can for example be carried out by heating said structure to around 900°C in gaseous oxygen.
 - 30 ✓ following this oxidation, a layer of oxide is then formed on the thin layer.

➤ annealing of the structure at around 1100°C for two hours, in an argon atmosphere. This annealing simultaneously allows:

- ✓ reinforcing the interface between the support substrate and the face of the donor substrate which has undergone implantation, and
- ✓ curing certain defects generated during the implantation and detachment stages.

- a deoxidation operation, which is carried out following thermal treatment, so as to withdraw the layer of oxide formed during the oxidation operation.

Such deoxidation, known per se, can be performed by immersing the structure for several minutes into a solution of fluorhydric acid at 10% or 20%, for example.

It will be noted that the oxide layer formed during oxidation helps to protect the underlying thin layer during annealing.

It will also be noted that a part of the thin layer, in the vicinity of its free surface, is therefore consumed during such a StabOx operation.

By implementing a StabOx step, during the finishing step, in addition to the RTA step, the process according to the present invention in particular permits:

- the concentration of defects in the thin layer to be reduced even more, and
- the structure to be brought to the planned thickness for the finished product.

In effect, as mentioned already, the RTA annealing aids in reconstructing the surface of the thin layer, and in rectifying certain defects in the thickness of the latter.

If this curing can, in certain cases, be partial only, then carrying out a supplementary StabOx step enables the material comprising a large part of the defects located in the vicinity of the free surface of the thin layer and in the thickness of the latter to be removed.

This corresponds still to an improvement in the quality of the structure.

This variant of the process according to the present invention, in which the finishing step comprises a RTA step and at least one StabOx step, is therefore particularly advantageous when there is a gradient of concentration for the defects increasing in the direction of the free surface of the thin layer, and a significant concentration of defects in the vicinity of this surface.

It will be noted that the total thickness consumed by one or more StabOx/deoxidation sequences can be advantageously controlled in order to eliminate all the defects and to bring the structure to the desired thickness.

According to a particularly advantageous embodiment of the invention, a StabOx step is carried out during the finishing stage and prior to the RTA step.

This RTA/StabOx sequence results in better oxidation uniformity when the StabOx step is carried out directly after detachment, without implementing it before the smoothing RTA step.

In effect, when a RTA step is implemented prior to a StabOx step, the surface roughness is less and the surface of the thin layer is more uniform.

In this way the speed of oxidation is close to that obtained when a polished structure is oxidised, and is furthermore the same at any point in the structure.

In addition, it can be useful to cure the crystalline defects present in the thin layer (owing to RTA) before consuming its thickness (during the StabOx/deoxidation sequence).

This is all the more interesting when the thin layer is particularly fine, and when consumption of its thickness is likely for example to punch holes not previously cured and restopped by RTA annealing.

In accordance with other embodiments of the invention, the finishing stage comprises at least one RTA operation, and can consist of one of the following sequences:

- RTA/StabOx (as just discussed);
- repetition of several RTA/StabOx sequences (the embodiment example discussed hereinafter comprising, in succession, two of these RTA/StabOx sequences);
- StabOx/RTA;
- StabOx/RTA/StabOx/RTA.

When the finishing stage comprises at least one additional RTA treatment (as can be the case when RTA/StabOx or StabOx/RTA sequences are repeated several times), the additional RTA treatment allows continued polishing of the free surface of the thin layer.

Said additional RTA treatment can also be carried out at a lower temperature (for example 1000 to 1100°C) than initial RTA treatment.

It is therefore possible to reduce the thermal budget of the repetition of the sequences mentioned

hereinabove by performing RTA treatment at lower temperature.

According to a particular embodiment of the invention, a so-called simple oxidation operation is carried out in place of a StabOx step such as mentioned above.

This simple oxidation operation successively comprises an oxidation stage and a deoxidation stage.

The thermal budget can then also be reduced since the second StabOx operation (thermal annealing over two hours approximately) is not utilised.

The reduction in the thermal budget is advantageous, in that it allows the constraints applied to the structure to be limited, reducing the probability of generating defects of dislocation type or slip lines in the crystallographic arrangement of the structure.

The oxidation stage followed by the deoxidation stage can therefore replace the StabOx step in all the chain formations mentioned hereinabove.

An embodiment of the process according to the present invention will now be described in detail hereinbelow, by way of non-limiting example.

This embodiment relates to the production of S1, S2, S3 structures comprising a thin layer on a support substrate.

The thickness of the thin layer of these respective structures is between 50 and 2000 Angströms, the total thickness of these structures being around 700 μm .

These S1, S2, S3 structures are produced by carrying out, during the implantation of species step, a co-implantation of helium then of hydrogen, with respective doses of:

- helium, $0.7 \cdot 10^{16} \cdot \text{cm}^{-2}$ and hydrogen, $0.9 \cdot 10^{16} \cdot \text{cm}^{-2}$ for the S1 structure;
- helium, $0.8 \cdot 10^{16} \cdot \text{cm}^{-2}$ and hydrogen, $0.9 \cdot 10^{16} \cdot \text{cm}^{-2}$ for the S2 structure;
- 5 • helium, $0.9 \cdot 10^{16} \cdot \text{cm}^{-2}$ and hydrogen, $0.9 \cdot 10^{16} \cdot \text{cm}^{-2}$ for the S3 structure.

By way of comparison, a S4 structure is produced via implantation of hydrogen alone, with a dose of $5.5 \cdot 10^{16} \cdot \text{cm}^{-2}$, that is a dose almost three times greater
 10 than the total dose implanted during co-implantation.

A common advantage of the co-implantation technique is disclosed here, with reduction by a factor of 3 approximately of the implanted dose relative to implantation of a single type of species.

15 This reduction translates by reduction in the implantation time, and finally in costs associated with production of structures comprising a thin layer on a support substrate, in particular by means of a transfer process of the SMARTCUT[®] type.

20 This known advantage, for example disclosed in the document by Aditya Agarwal, T. E. Haynes, V. C. Venezia, O. W. Holland, and D. J. Eaglesham, "Efficient production of silicon-on-insulator films by co-implantation of He+ with H+", Applied Physics Letters,
 25 vol. 72 (1998), pp. 1086-1088, in which it is established that the co-implantation of hydrogen and helium aids in decreasing the doses that have to be implanted.

It has to be noted that it is also stated in this
 30 document that the superficial SOI layer obtained by co-implantation of hydrogen and helium exhibits roughness

comparable to that of the surface SOI layer obtained by implantation of just hydrogen.

The document just discussed above does not therefore bring about any improvement in surface roughness, due to co-implantation (and a fortiori does not seemingly propose exploitation of such an effect).

With reference now to the description of the invention, following the co-implantation step, as already mentioned, the classic steps of close contact placing and detachment are carried out, then a finishing step comprising at least a RTA, so as to obtain the final S1, S2, S3. S4 structures.

PSD roughness measurements of each of these structures were done with the aid of an AFM microscope.

Figure 1 shows the power of the different spectral constituents of the roughness of each of the S1, S2, S3, S4 structures.

The abscissae axis shown in the diagram in Figure 1 is therefore the spatial period (in μm), which describes the roughness frequencies observed, from high frequencies (to the left of this axis) to low frequencies (to the right of this axis).

These measurements have more precisely been done at the edge of the structure, that is, at the level of the zone, where detachment is triggered during the detachment step, with this zone consequently having a generally relatively severe roughness.

Figure 1 shows the result of such measurements on a swept surface of $40 \times 40 \mu\text{m}^2$ (this surface of $40 \times 40 \mu\text{m}^2$ therefore corresponding to the maximum frequency according to which the roughness can be observed).

Figure 1 therefore shows the difference in roughness between the S1, S2, S3, S4 structures, after the RTA treatment of the finishing step of said structures.

5 A first curve C4 illustrates the roughness of the S4 structure classically made by implantation of hydrogen alone.

Three other curves C1, C2, C3 illustrate the roughness of structures S1, S2 and S3 respectively
10 produced by the process according to the present invention, combining co-implantation and RTA annealing.

These three curves C1, C2, C3 correspond to different doses of co-implanted species.

Figure 1 characterises the fracture facies via
15 analysis of the frequencies comprising roughness, and demonstrates the advantage gained by the association, according to the present invention, of co-implantation with RTA.

Figure 1 effectively confirms that low-frequencies
20 roughness of the S1, S2 and S3 structures produced according to the present invention is substantially lower than that of the S4 structure produced conventionally.

A net decrease in roughness for spatial periods of
25 substantially between 3 and 15 μm is observed in particular.

Co-implantation therefore enables low-frequencies roughness to be limited, while high-frequencies roughness is equivalent, or slightly less, in the case
30 of implantation of hydrogen alone.

The succession according to the present invention of the co-implantation/contact/detachment/RTA steps

therefore allows roughness which is overall weaker than in the case of the known succession of the implantation of hydrogen alone/contact/detachment/RTA steps.

It is also possible to vary the implantation doses of the co-implanted species (in particular the dose of helium in the example presented here) while preserving low-frequencies roughness lower than that conventionally noted.

According to the embodiment of the process according to the present invention detailed here, the finishing step comprises, apart from the RTA step, successive StabOx, RTA and StabOx steps (or a finishing stage comprising repetition of two RTA/StabOx sequences).

As it has already been shown, such a finishing stage allows:

- consuming the thickness of the thin layer and reducing the residual implantation defects under the surface after detachment;
- consolidating the thin layer/support substrate adhesion interface via annealing carried out during the StabOx stages;
- bring the structure to the desired thickness for the finished product;
- continuing to smooth the surface by way of additional RTA treatment.

Figure 2 makes comparison of RMS surface roughness of the structure of type S3 obtained by the embodiment according to the present invention to that of the surface of the structure of S4 type obtained by a conventional process.

Roughness measurements have been done using an AFM microscope sweeping surfaces of $10 \times 10 \text{ } \mu\text{m}^2$ and $40 \times 40 \text{ } \mu\text{m}^2$ both at the centre of the structures as well as at their edge (i.e. a zone where detachment is triggered).

5 In Figure 2 (axis of ordinates in RMS Angströms), the bars in the first plane show the roughness measured for the S3 type structure, whereas the bars in the second plane represent roughness measured for the S4 type structure.

10 In Figure 2, a net decrease in roughness for the S3 structure is observed, especially for low spatial frequencies.

15 Figures 3a and 3b are representations similar to that of Figure 1, and illustrate the reduction in roughness obtained according to the present invention, respectively in the centre of a structure and at the edge of this structure.

20 Figures 3a and 3b allow comparison of the PSD roughness of a structure of the S3 type obtained by implementing the invention to that of a structure of the S4 type obtained by a classic process both at the centre of said structures (Figure 3a), as well as at their edge (Figure 3b).

The swept surfaces had dimensions of $40 \times 40 \text{ } \mu\text{m}^2$.

25 It can be observed in each of Figures 3a and 3b that the roughness of the structure S3 is less than that of the structure S4, especially at low spatial frequencies (in particular when the spatial period is between 3 and $15 \text{ } \mu\text{m}$).

30 Roughness uniformity which is better for the S3 structure than for the S4 structure is also noted (the

differences in uniformity between the edge and the centre of the S3 structure are effectively attenuated).

It is noted that the process according to the present invention constitutes an original approach which
5 allows significant roughness to be prevented (in particular at low-frequency).

In this the invention differs from known treatment which is "curative", to the extent that it intervenes to "take up" with a given roughness.

CLAIMS

1. A process for producing a structure comprising a thin layer of semiconductor material on a substrate, comprising the following stages:

- 5 • carrying out implantation of species under a face of a donor substrate from which the thin layer must be made, so as to create an embrittlement zone in the thickness of the donor substrate,
- 10 • placing the face of the donor substrate in close contact with a support substrate, after it has undergone implantation,
- 15 • detaching the donor substrate at the embrittlement zone, to transfer a part of the donor substrate onto the support substrate and form the thin layer on the latter,
- 15 characterised in that:
 - 20 • the implantation stage carries out a co-implantation of at least two different atomic species so as to minimise the low-frequencies roughnesses at the level of the structure obtained after detachment;
 - 25 • and the process further comprises a finishing step comprising at least one rapid thermal annealing operation carried out in an atmosphere of pure argon, of pure hydrogen or comprising a mixture of argon and hydrogen so as to minimise the high-frequencies roughnesses at the level of the structure obtained after detachment.

2. The process as claimed in the preceding claim, characterised in that the hydrogen and helium species are co-implanted during said implantation step.

5 3. The process as claimed in the preceding claim, characterised in that said hydrogen and helium species are implanted sequentially.

10 4. The process as claimed in the preceding claim, characterised in that the helium is implanted before the hydrogen.

15 5. The process as claimed in any one of Claims 2 to 4, characterised in that the dose of implanted helium is substantially between $0.7 \cdot 10^{16} \cdot \text{cm}^{-2}$ and $1.2 \cdot 10^{16} \cdot \text{cm}^{-2}$, and in that the dose of implanted hydrogen is substantially between $0.7 \cdot 10^{16} \cdot \text{cm}^{-2}$ and $2 \cdot 10^{16} \cdot \text{cm}^{-2}$.

20 6. The process as claimed in any one of the preceding claims, characterised in that the rapid thermal annealing (RTA) is carried out at a temperature of between 900°C and 1300°C for 1 to 60 seconds.

25 7. The process as claimed in any one of the preceding claims, characterised in that said finishing stage further comprises at least one operation of stabilised oxidation StabOx of the structure obtained after detachment.

30 8. The process as claimed in the preceding claim, characterised in that said StabOx operation

successively implements an oxidation operation, an annealing operation and a deoxidation operation.

9. The process as claimed in the preceding claim,
5 characterised in that said annealing operation is carried out during two hours at a temperature of around 1100°C.

10. The process as claimed in any one of Claims 7
10 to 9, characterised in that, during the finishing stage, the RTA annealing operation is carried out prior to the StabOx operation.

11. The process as claimed in the preceding claim,
15 characterised in that said finishing stage comprises a plurality of RTA/StabOx sequences.

12. The process as claimed in any one of Claims 7
to 9, characterised in that during the finishing stage,
20 the StabOx operation is carried out prior to the RTA annealing operation.

13. The process as claimed in the preceding claim,
characterised in that said finishing stage comprises a
25 plurality of StabOx/RTA sequences.

14. The process as claimed in any one of Claims 1
to 6, characterised in that said finishing stage also
comprises at least one simple oxidation operation, said
30 simple oxidation operation comprising an oxidation operation of the structure obtained after detachment followed by a deoxidation operation.

15. The process as claimed in the preceding claim, characterised in that during the finishing stage, the RTA operation is carried out prior to said simple oxidation.

16. The process as claimed in the preceding claim, characterised in that said finishing stage comprises a plurality of RTA/simple oxidation sequences.

17. The process as claimed in Claim 14, characterised in that, during the finishing stage, said simple oxidation is carried out prior to the RTA annealing operation.

18. The process as claimed in the preceding claim, characterised in that said finishing stage comprises a plurality of simple oxidation/RTA sequences.

19. A structure produced by the process as claimed in any one of the preceding claims, characterised in that the thin layer exhibits a small low-frequencies roughness, particularly a roughness measured by sweeping a surface of $40 \times 40 \mu\text{m}^2$, substantially comprised between 4 and 5 Angströms RMS.