

**METHOD FOR IMPLANTATION THROUGH AN IRREGULAR SURFACE**

5 The present invention relates to the treatment of wafers made of materials chosen from semiconductors, especially for applications in electronics, microelectronics and optoelectronics.

10 More precisely, the invention relates to a method of implantation in a wafer comprising at least one layer having an irregular surface, said implantation passing through said irregular surface.

15 It is known to carry out implantation methods in wafers of materials chosen from semiconductors in order to obtain various effects.

For example, it may be desirable to create a weakened zone in the thickness of the wafer by implantation.

20 The SmartCut[®] process thus employs such an implantation for creating a weakened zone.

25 A general description of the SmartCut[®] process will be found in "Silicon-On-Insulator Technology: Materials to VLSI", 2nd Edition by Jean-Pierre Colinge, published by Kluwer Academic Publishers, p. 50 and 51.

30 If the aim is to create a weakened zone in the thickness of the wafer (for example within the context of a SmartCut[®] process), it is generally desirable for said zone to be regular by lying approximately in the same plane.

35 More generally, in many implantation applications, it is desirable to carry out the implantation in such a way that the implanted species are distributed in the thickness of the wafer in a regular distribution, with



the same implantation depth beneath the mean level of the wafer surface.

However, implantation through an irregular surface
5 disturbs the uniformity of the depth of implantation of these species.

This effect is illustrated in figure 1.

10 This figure illustrates the implantation of species in a wafer 10 through a layer 12 of material having an irregular surface 120 and through part of the substrate 11 on which the layer 12 lies.

15 It should be pointed out that the term "irregular surface" is understood in this text to mean a surface having an rms (root mean square) roughness and a planarity greater than a value of the order of a few ångstroms.

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In contrast, in the present text a surface will be said to be regular if its roughness is less than this value.

It is found that because the surface 120 is irregular
25 in character, the implantation depth (represented by the line 13) is also irregular.

This constitutes a drawback.

30 It is an object of the invention to alleviate this drawback.

To achieve this object, the invention proposes a method of implantation in a wafer comprising at least one
35 layer having an irregular surface, said implantation passing through said irregular surface, characterized in that the method includes, prior to the implantation step, a step in which said irregular surface is coated with a coating layer in order to increase the

uniformity of the implantation depth.

Other aspects, objects and advantages of the invention will become apparent on reading the following description of the invention given with reference to the appended drawings, in which, apart from figure 1 that has already been commented upon:

- figure 2 illustrates the effect of producing a coating layer, prior to implantation, on the uniformity of implantation depth;
- figure 3 shows results of simulations illustrating the effects on the local implantation depth of the thickness of the coating layer and of the planarization of this coating layer; and
- figure 4 is a graph showing the differences in implantation depth coefficients of various materials for hydrogen implantation.

Figure 2 shows a wafer 20 that includes a layer 22 having an irregular surface 220 on a substrate layer 21.

This figure shows that a layer 25 covers the irregular surface 220.

The layer 22 may for example be made of CVD diamond, of Si_3N_4 , of AlN or of a polycrystalline material, such as especially polycrystalline silicon.

Such materials are rough. For example, they may be used in a wafer of the SOI (Silicon On Insulator) type, for example to improve the thermal conductivity properties of such a wafer.

It may thus be desirable to make the insulation layer of such a wafer not from SiO_2 (whose thermal conductivity properties are not good) but by one or more materials that possess a high thermal conductivity, such as diamond or Si_3N_4 .

Layers of such materials are generally obtained by epitaxy. However, the surface of such epilayers is irregular.

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The material of the layer 22 is typically a material that has a high hardness (for example in the case of diamond) or is tricky to polish uniformly as it is heterogeneous (example of polycrystalline materials) and consequently difficult to polish or in general to planarize.

In particular it may be a costly material for which it is desirable to minimize as far as possible any losses of material.

The layer 22 may have been obtained by deposition on the plane surface of the layer 21 of the substrate.

Such deposition may for example be carried out using a CVD (chemical vapor deposition) technique.

It should be pointed out that the layer 22 is therefore a layer whose surface 220 is certainly irregular but whose other face 221 at the interface with the substrate 21 is itself plane.

The face of the substrate 21 that receives the deposited layer 22 is in fact itself plane.

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In the method of implementation of the invention shown in this figure, the wafer 20 is a multilayer wafer composed of a plurality of layers (in this case, layer 22 + substrate layer 21).

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However, it should be noted that it is possible to implement the invention in order to carry out uniform implantation in a monolayer wafer having an irregular surface, or even within a layer having an irregular

surface and lying on or in a multilayer wafer.

Returning to the method of implementation of the invention illustrated in figure 2, the wafer 20 thus includes, beneath the layer 22, a layer 21 called the substrate.

In this method of implementing the invention, the implantation is carried out so as to pass through the layer 22 having an irregular surface, in order to form, in the thickness of the substrate 21, a zone 23 corresponding to the maximum concentration of the implanted species.

This coating layer has been added to the wafer 20 before implantation.

In particular, this may be produced by deposition of the material of the coating layer 25.

It should be noted that the surface 250 of the coating layer 25 is plane.

This may be achieved in particular by carrying out a treatment of this surface 250.

Such a treatment may thus include a planarization treatment, for example involving a polishing operation.

It may be seen in figure 2 that the zone 23 is much more regular than the zone 13 in figure 1.

The fact of having coated the irregular surface of the layer 22 with a layer having a plane surface, before the implantation step, means in fact that this implantation can then be carried out with an implantation depth of substantially improved uniformity.

Within the context of creating a weakened zone corresponding to the zone 23 having a maximum concentration of implanted species, a regular weakened zone 23 may therefore be produced by implantation, while carrying out this implantation through a layer 22 of irregular surface. This operation may be advantageous, especially within the context of implementing the invention for carrying out a SmartCut® process.

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The invention may thus be carried out within the context of a SmartCut® process. In this case, after the implantation the following main steps are carried out:

- bonding of a stiffener to the surface 250;
 - 15 • detachment of the substrate 21 in the zone 23;
- and
- optionally, treatment of the free surface thus created in this zone 23.

20 It should also be mentioned that in this case it is possible, before the bonding, to insert a thin electrically insulating film between the surface 250 and the stiffener.

25 This may be accomplished for example by depositing an electrically insulating film - for example made of SiO_2 - on the surface 250.

In such a case, the combination of the layer 25 and the additional film imposed thereon may be likened to the coating layer.

The abovementioned thin insulating film may be deposited before implantation on the coating material that is already present on top of the surface 220, in such a way that said thin film then forms part of the layer 25 (see in this regard the cases illustrated in figure 3).

In general, the coating layer 25 may consist of a plurality of layers of different materials. This aspect will be discussed later in the text.

5 In the application of the invention employing a SmartCut[®] process, the substrate 21 may be made of single-crystal silicon. This may also be the case for other applications of the invention.

10 The implantation may be carried out with hydrogen and/or helium. This is in particular the case if the invention is used for implementing a SmartCut[®] process.

Figure 3 illustrates the effect on the local
15 implantation depth of the thickness of the coating layer and of the planarization of this coating layer.

This layer represents, for four local implantation conditions, the implantation depth through a coating
20 layer 25 and through a layer 22 having an irregular surface, into the thickness of a substrate 21 (these references 21, 22, 25 corresponding to the various layers illustrated in figure 2).

25 These results come from simulations performed by the Applicant.

In these simulations:

- the layer 21 had the characteristics of single-
30 crystal silicon;
- the layer 22 had the characteristics of carbon, and thus corresponded to the layer having an irregular surface (the carbon corresponding to diamond);
- the layer 25 was composed of two layers:
35 > a silicon layer deposited on the irregular surface of the carbon layer 22 (the irregularities of this layer corresponding in figure 3 to the various carbon thicknesses in the various simulations) and

➤ an SiO_2 layer coating the silicon layer.

The four simulations shown in figure 3 correspond to four hydrogen implantation conditions:

- 5 • case 1 corresponds to a carbon thickness of 2000 ångströms, coated with 2000 ångströms of silicon and 1000 ångströms of SiO_2 . In this case, the implantation depth in the silicon of the substrate 21 is 1170 ångströms;
- 10 • case 2 corresponds to a carbon thickness of 1000 ångströms, coated with 2000 ångströms of silicon and 1000 ångströms of SiO_2 . In this case, the implantation depth in the silicon of the substrate 21 is 2793 ångströms;
- 15 • case 3 corresponds to a carbon thickness of 2000 ångströms, coated with 1000 ångströms of silicon and 1000 ångströms of SiO_2 . In this case, the implantation depth in the silicon of the substrate 21 is 2383 ångströms; and
- 20 • case 4 corresponds to a carbon thickness of 1000 ångströms, coated with 1000 ångströms of silicon and 1000 ångströms of SiO_2 . In this case, the implantation depth in the silicon of the substrate 21 is 3865 ångströms.

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It should be pointed out that the implantation conditions (dose, energy, etc.) are the same in the four cases.

30 These results illustrate a number of effects:

- firstly, starting with an irregular surface, when implantation takes place through the surface of layer 22 that has an irregularity and through a coating layer, which is the same for the various points on this surface, the irregularity of the layer 22 is not only reproduced but even magnified. This is illustrated:

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➤ by comparing cases 1 and 2, which shows a difference of 1623 ångströms in the implantation depth, starting from an initial

difference of 1000 ångstroms in the thickness of the carbon layer and

5 > by comparing cases 3 and 4, which shows a difference of 1482 ångstroms in the implantation depth, starting from an initial difference of 1000 ångstroms in the thickness of the carbon layer;

• secondly, in the case in which, starting with an irregular surface of the layer 22, by planarizing the coating layer 25 the difference in implantation depth is very substantially reduced;

15 > comparing cases 2 and 3 thus illustrates a difference of only 410 ångstroms in the implantation depth, starting from a difference of 1000 ångstroms in the thickness of the layer 22. Comparing cases 2 and 3 corresponds to a situation in which the silicon layer that contributes to forming the coating layer 25 has been planarized before deposition of the SiO₂ layer that coats it. Comparing these two cases thus illustrates the benefit of such a planarization.

It will therefore be understood that, to minimize the differences in implantation depth that are generated by the differences in thickness of the layer 22, a planarized coating is particularly advantageous.

It should also be mentioned that it is possible, according to an alternative method of implementing the invention, to locally adapt the thickness of the coating layer 25 at various points on the wafer, so as as a consequence to selectively adapt the implantation depth for the purpose of further increasing its uniformity.

This local adaptation of the thickness of the coating layer 25 may be achieved while depositing this layer, or by subsequent treatments (selective chemical etching

or planarization, etc.).

The implementation of the invention has been discussed with reference to figure 3 for coating with a layer 25 based on Si and SiO₂.

As will now be seen, the nature of the material(s) used for this coating layer may also have an influence on the differences in implantation thickness.

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Thus, figure 4 illustrates the mean implantation depth (Rp(Å) in ångstroms plotted on the y-axis) as a function of the implantation energy (implantation energy in keV, plotted on the x-axis) for hydrogen 15 implantation into various materials.

This figure shows that, for the same implantation conditions, the mean implantation depth differs according to the nature of the implanted material.

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Each material may thus be characterized by an implantation depth coefficient specific thereto.

Figure 4 thus illustrates that the following materials 25 may be classified in decreasing order of this coefficient (that is to say for the same implantation conditions, the material having a higher coefficient will correspond to a greater implantation depth):

- SiO₂;
- 30 • Si;
- germanium;
- carbon (diamond);
- aluminum oxide.

35 These differences in implantation depth coefficient may advantageously be exploited within the context of the invention.

This is because the Applicant has demonstrated that it

is possible to further improve the uniformity of the implantation by coating with a layer 25 made of one or more materials, in which each material has an implantation depth coefficient as close as possible to
5 the implantation depth coefficient of the material of the layer 22 having an irregular surface.

Coating with such a layer 25 and planarizing this coating layer (preferably by including a polishing
10 step) results in the optimum conditions for minimizing the differences in implantation depth that are generated by the differences in thickness of the layer 22.

15 In this case, an "overall layer" made up of the superposition of the layers 22 and 25 is deposited. This overall layer has a constant thickness (because of the planarization) and an implantation depth coefficient that is as uniform as possible.

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It should be pointed out that it is also possible to combine, within the layer 25, a plurality of layers of different materials in such a way that the average of the implantation depth coefficients of these various
25 materials corresponds to the value of the implantation depth coefficient of the irregular layer 22 to be coated.

The abovementioned "average" may be weighted by the
30 respective thicknesses of the various layers making up the layer 25.

CLAIMS

1. A method of implantation in a wafer comprising at least one layer having an irregular surface, said
5 implantation passing through said irregular surface, characterized in that the method includes, prior to the implantation step, a step in which said irregular surface is coated with a coating layer in order to increase the uniformity of the implantation depth.
- 10 2. The method as claimed in the preceding claim, characterized in that the wafer is a multilayer wafer that includes at least one substrate and said layer having an irregular surface.
- 15 3. The method as claimed in one of the preceding claims, characterized in that the implantation is carried out so as to pass through the layer having an irregular surface.
- 20 4. The method as claimed in one of the preceding claims, characterized in that the coating layer is deposited on said irregular surface.
- 25 5. The method as claimed in one of the preceding claims, characterized in that the nature of the coating material(s) is chosen so as to increase the uniformity of the implantation depth.
- 30 6. The method as claimed in the preceding claim, characterized in that the choice of coating material(s) is made so as to minimize the difference between the implantation depth coefficient of the material of the layer having an irregular surface and the implantation
35 depth coefficient of the coating material(s).
7. The method as claimed in one of the preceding claims, characterized in that, during the coating step,

the coating layer is produced so as to give this layer a plane surface.

8. The method as claimed in one of the preceding
5 claims, characterized in that, during the coating step, a treatment of the surface of the coating layer is carried out.

9. The method as claimed in the preceding claim,
10 characterized in that said treatment is a planarization treatment.

10. The method as claimed in the preceding claim,
characterized in that said treatment includes a
15 polishing operation.

11. The method as claimed in one of the preceding
claims, characterized in that the implantation is
carried out with hydrogen and/or helium.
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12. The method as claimed in one of the preceding
claims, characterized in that the aim of the
implantation is to form a zone of maximum concentration
of the implanted species that corresponds to a weakened
25 zone.

13. The method as claimed in one of the preceding
claims, characterized in that a SmartCut[®] process is
carried out after the implantation.
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14. The method as claimed in one of the preceding
claims, characterized in that the layer of material
having an irregular surface is made of one of the
following materials: diamond, Si₃N₄, AlN,
35 polycrystalline silicon.