

DESCRIPTION

TITLE: PROCESS FOR THINNING THE SURFACE LAYER OF AN SOI SUBSTRATE

FIELD OF THE INVENTION

The present invention relates to the field of semiconductors and in particular of SOI substrates (SOI standing for silicon-on-insulator). The invention relates to a process for thinning the surface layer of an SOI substrate in a single-wafer chemical processing tool, which process is optimized to achieve a surface-layer non-uniformity less than or equal to ± 0.4 nm.

TECHNOLOGICAL BACKGROUND OF THE INVENTION

More and more applications based on SOI substrates require the thickness of the silicon surface layer (also called the active layer below) to have a very high uniformity. For example, in digital applications, the active layer of FDSOI substrates (FDSOI standing for fully depleted SOI) must exhibit very small variations in thickness because such variations have an impact on the threshold voltage of transistors produced in and/or on the active layer; in photonic applications, the performance of filters or modulators is also strongly influenced by non-uniformities in the thickness of the active layer of the SOI substrate.

The specifications in terms of thickness and uniformity therefore get very demanding: for active layers with thicknesses typically less than 50 nm, WiW and WtW non-uniformities (WiW standing for within-wafer and WtW standing for wafer-to-wafer) are expected to typically be less than ± 0.4 nm, i.e. every measured point of the layer must lie within ± 0.4 nm of its average thickness, excluding a peripheral zone of a few mm. Such uniformities are difficult to achieve because the contributions to the non-uniformity of the surface layer of the succession of steps used to fabricate the SOI substrate add up.

One known solution for correcting non-uniformities in the thickness of the active layer is to carry out localized etching of said layer, using plasma etch processes as described, for example, in document US20140234992, or using cluster-ion-beam etch processes as in particular described in document WO2013003745. However, this type of solution has a drawback: the etching of the surface of the active layer creates a surface layer of amorphous silicon which is liable to cause electrical problems and which must therefore be removed. The removal of the amorphous layer leads to an increase in surface roughness, which negatively affects the performance of the device produced on the thin layer.

Document WO2004015759 proposes an alternative solution, implementing localized sacrificial thermal oxidation, which locally consumes a greater or lesser thickness of the active layer so as to correct its thickness non-uniformities. The drawback of this approach is that a local temperature gradient is not easy to introduce into a silicon layer: the resolution of the correction of non-uniformities may therefore be limited.

Document WO2013175278 also aims to improve the thickness uniformity of the surface layer of an SOI substrate, through implementation of an SC1 chemical etching solution: the amount of solution dispensed, the application time and/or the temperature are adjusted depending on the thickness of the layer to etch. Document EP3200219 describes a solution for thinning the active layer of an SOI substrate, in a single-wafer etching tool, achieving a WiW non-uniformity of about ± 0.5 nm.

It remains advantageous to improve processes for thinning the active layer of an SOI substrate, to ensure excellent thickness uniformities (better than ± 0.5 nm, or even than ± 0.4 nm), for very small thicknesses and for SOI-substrate diameters of at least 200 mm, or even 300 mm.

OBJECT OF THE INVENTION

The present invention aims to improve the uniformity of the surface layer of an SOI substrate, without decreasing the performance of said layer (roughness and number of defects), and to provide an industrial solution both in terms of reliability and cost. In particular it relates to a process for thinning the surface layer of an SOI substrate in a single-wafer chemical processing tool, which process is optimized to achieve a surface-layer non-uniformity less than or equal to ± 0.4 nm, with a yield at least equal to 90%.

BRIEF DESCRIPTION OF THE INVENTION

The invention relates to a process for thinning a surface layer of an SOI substrate, comprising:

a) a step of measuring the thickness of the surface layer, to obtain an average thickness and a thickness non-uniformity of said layer,

then the following steps, which are performed in a single-wafer chemical processing tool and during which the SOI substrate is rotated:

b) applying n cycles, with n a integer greater than or equal to 1, of oxidation and etching, to a front side of the surface layer, each cycle involving dispensing ozonated water then dispensing hydrofluoric acid,

c) carrying out a non-uniform etch on the front side of the surface layer, this involving dispensing a silicon-etching solution at a temperature between 20°C and 80°C, in a central region of the surface layer, for a given time, called the non-uniform etching time,

d) carrying out a uniform etch on the front side of the surface layer, this involving dispensing a silicon-etching solution with a sweeping movement from the edge to the center of the surface layer and back again, at a temperature between 20°C and 80°C, for a given time, called the uniform etching time.

Given the average thickness and thickness non-uniformity of the surface layer, the number of cycles, the non-uniform etching time and the uniform etching time are determined, before carrying out steps b), c) and d), on the basis of a model relating them to an average etched thickness of the surface layer and to an average etching non-uniformity defined as the difference between an average etched thickness in a central region of the surface layer and an average etched thickness in a peripheral region of the surface layer.

According to other advantageous and non-limiting features of the invention, taken individually or according to any technically feasible combination:

- the average etching non-uniformity is positive;
- the central region and peripheral region correspond respectively to 30% and 70% of the area of the surface layer;
- the average etched thickness and the average etching non-uniformity are each expressed in a quadratic form, as a function of variables which are the number of cycles, the non-uniform etching time and the uniform etching time;
- the model for determining the number of cycles, the non-uniform etching time and the uniform etching time is a three-objective optimization model with lexicographic optimality;
- said objectives are:
 - (i) identifying a first set of solutions (non-uniform etching time; uniform etching time) making it possible to achieve equality between the average etched thickness of surface layer and a target average thickness to etch, for any number of cycles, said target average thickness to etch being defined as the difference between the target average thickness of the surface layer and the average thickness measured in step a);
 - (ii) restricting the first set of solutions (non-uniform etching time; uniform etching time) identified in (i), to a second set of solutions (non-uniform etching time; uniform etching time) making it possible to minimize the difference between the average etching non-uniformity and a target

average etching non-uniformity, for any number of cycles, the target average etching non-uniformity being defined as the difference between a target thickness non-uniformity for the surface layer and the thickness non-uniformity measured in step a),

(iii) selecting a recipe from the second set of solutions defined in (ii) making it possible to maximize the number of cycles;

- steps b), c) and d) are performed in order;
- the temperature in steps c) and d) is set to 65°C;
- in step c), the silicon-etching solution is dispensed solely at the center, or with a sweeping movement from the center to 50% of the radius of the surface layer and back again;
- the average etching non-uniformity depends on an etch-rate gradient defined between the center and the edge of the surface layer, said gradient being dependent:
 - on a flow rate of the silicon-etching solution in step c), and/or
 - on whether a solution on the back side of the SOI substrate during all or part of step c), and/or
 - on the temperature applied in step c);
- the silicon-etching solution in step c) and/or step d) is SC1.

BRIEF DESCRIPTION OF THE FIGURES

Further features and advantages of the invention will become apparent from the following detailed description of the invention, which is given with reference to the appended figures, in which:

[Fig. 1] Figure 1 shows three examples of surface-layer-thickness maps, after conventional thinning sequences, before implementation of a thinning process according to the present invention; the grayscale is in angströms in the figure;

[Fig. 2a]

[Fig. 2b] Figure 2a and figure 2b illustrate the non-uniformity of the surface layers of 25 SOI substrates before (Av) and after (Ap) implementation of a thinning process according to the present invention; figure 2a shows the deviations in thickness (expressed in angströms) measured with respect to the average thickness, as a function of the radius of the substrates, and figure 2b show the stacked maps of the surface layers of 25 SOI substrates, before (Av) and after (Ap) steps b), c), d) of the process according

to the invention have been carried out. The maps are derived from a thickness measurement at 625 points.

DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to a process for thinning the surface layer of an SOI substrate, formed from an active layer made of high-quality single-crystal silicon, placed on a silicon-oxide layer, itself placed on a carrier substrate, conventionally made of single-crystal silicon.

There are a number of known methods for fabricating such a substrate, these methods including the Smart Cut™ process, which is based on implantation of light species, to create a buried fragile plane in a donor substrate, and on use of direct bonding to join the donor substrate and a carrier substrate with a dielectric layer placed between these two substrates. Transferring a thin layer from the donor substrate to the carrier substrate makes it possible to obtain the SOI substrate, the rest of the donor substrate being able to be reused for a plurality of subsequent transfers.

The donor and carrier substrates preferably each take the form of a circular wafer having a diameter of 200 mm or 300 mm, or even 450 mm, and a thickness typically of between 500 and 900 microns.

Immediately after the transfer, the free surface of the thin surface layer has a relatively high level of roughness (about 4 to 8 nm RMS as measured with an atomic force microscope (AFM) in a scan area of 30 x 30 microns) for a layer thickness, for example, of about 250 nm. Surface finishing techniques must then be implemented to heal the layer and thin it to a target thickness less than or equal to 50 nm - for example 20 nm, 15 nm or even 10 nm. Among finishing techniques, it is possible in particular to implement sacrificial oxidation heat treatments, etching and/or surface reconstruction (smoothing) under a neutral or reducing atmosphere. These treatments are in general carried out at high temperatures, for example the oxidation may be carried out between about 750°C and 1100°C, and the smoothing between 950°C and 1250°C.

One advantageous thinning, finishing sequence in particular comprises:

- stabilization, involving oxidizing the surface of the surface layer; the sacrificial oxide layer is then removed via chemical attack,
- thermal smoothing of the surface, under a neutral or reducing atmosphere,
- thinning with a new sacrificial oxidation of the surface of the surface layer.

These steps are carried out in batch processing furnaces and, although processes are continuously improved, the various contributions to non-uniformities add up, tending to generate out-of-specification active layers.

The present invention thus provides a thinning process that compensates at least in part for a thickness non-uniformity of the surface layer of an SOI substrate, this initial non-uniformity typically being less than 15 nm, or even less than 10 nm. The overall thinning caused by said process is low (in general, less than 5 nm, or even less than 3 nm): the process provided is therefore advantageously applied after a thinning, finishing sequence such as described above.

The process comprises a first step a) of measuring the thickness of the surface layer, to obtain an average thickness E_{mean} and a thickness non-uniformity U of said layer. The thickness measurement is taken at a plurality of points i distributed over the surface of the layer. The average thickness E_{mean} corresponds to the average of the thicknesses measured at the plurality of points i ; the thickness non-uniformity U expresses the thickness distribution of the layer at the plurality of points i . It is expressed in terms of a value of the deviation in thickness (at point i) with respect to the average thickness E_{mean} (for example ± 0.4 nm); in particular, a non-uniformity U of ± 0.4 nm indicates that the thicknesses of the surface layer at the plurality of points i lie within the interval $[E_{\text{mean}} - 0.4 \text{ nm}; E_{\text{mean}} + 0.4 \text{ nm}]$.

The number of measurement points i may be about 20, 100, 500 or even 1000, and measurements are preferably taken up to 3 mm from a peripheral edge of the SOI substrate, bearing in mind that the surface layer generally extends to at least 0.5 mm from said edge. The points i will possibly be distributed with a radial geometry, in a star, or with a spiral geometry starting from the center of the layer, or with any other geometry capable of effectively expressing the thickness non-uniformity of the measured layer.

Non-limitingly, the thickness measurement of step a) may be performed using known methods based on ellipsometry or reflectometry techniques, with or without the presence of a sacrificial oxide layer on the silicon surface layer.

Figure 1 shows three examples of surface-layer-thickness maps, after conventional thinning, finishing sequences, in various tools. As may be seen, in general, a radial non-uniformity, of greater or lesser amplitude (grayscale in angströms in the figure), and an excess central thickness results.

The following steps of the process according to the invention therefore advantageously make it possible to compensate for a layer profile having an excess central thickness. They are performed in a single-wafer chemical processing tool. Such a tool is well known and in particular comprises an arm for gripping the SOI substrate, one or more nozzles for dispensing various types of solutions (chemical solutions or water) onto the front side of the substrate (onto the side of the surface layer) and/or onto its back side. While solution is being dispensed, the substrate is made to rotate so as to distribute the solution over the entire side in question (typically at between 10 and 1000 revolutions per minute).

Steps b), c) and d), which will now be described, are performed in order (preferred) or out of order, but in all cases, one after another, without removal from the tool because the process according to the invention does not require intermediate thickness measurements, this being particularly advantageous.

It will be noted that, if the SOI substrate comprises a sacrificial oxide layer on the silicon surface layer, this oxide layer is removed prior to implementation of steps b), c) and d) of the process.

Step b) comprises applying n oxidation and etching cycles to the (free) front side of the surface layer, n being an integer greater than or equal to 1. Each cycle involves dispensing ozonated water then dispensing hydrofluoric acid (HF), so as to successively oxidize the surface layer and etch the oxide layer formed in each cycle. The surface layer is thinned by about 0.4 to 0.5 nm per cycle. Although the applicable number of cycles is not limited, it is preferable to apply between 1 and 10 cycles, or even advantageously between 1 and 5 cycles, to remain industrially viable.

Such a cycle is known, in substrate cleaning, by the acronym "SCROD" (standing for single-wafer spin cleaning with repetitive use of ozonated water and dilute HF).

Typically, the ozone concentration in ozonated water is between 20 and 40 ppm, and the mass concentration of the HF solution is between 0.5% and 4%; the dispensing flow rate is 2 liters per minute. Step b) is preferably performed at room temperature. The dispensing can be via a nozzle that is fixed or mobile (i.e. one making a sweeping motion).

A step of rinsing the back side of the SOI substrate may be performed in parallel to application of the aforementioned cycles to the front side.

Step c) corresponds to carrying out an etch on the front side of the surface layer, this involving dispensing a silicon-etching solution (for example SC1 (standing for standard clean standard 1), TMAH, HF/H₂O₂, HF/O₃, HF/HNO₃ + CH₃COOH, KOH, etc.) in a central region of the surface layer. The fact that the solution is dispensed only in the central region implies non-uniform etching of the surface layer, resulting in more etching in the central region than in the peripheral region.

An average etching non-uniformity u_{etch} is obtained at the end of steps b), c), d) of the process, which non-uniformity is defined as the difference between an average etched thickness in a central region of the surface layer $e_{\text{etch}}^{\text{C}}$ and an average etched thickness in a peripheral region of the surface layer $e_{\text{etch}}^{\text{P}}$. This etching non-uniformity u_{etch} is positive, so as to compensate for an excess central thickness of the surface layer. It is mainly related to step c), although the other steps are sometimes likely to add a small contribution.

In step c), the dispensing may be carried out solely at the center, or with a sweeping movement from the center to 30%, 50%, 80%, or even 90% of the radius of the surface layer and back again. By doing so, it is possible to adjust the profile of the etching non-uniformity between the central region and peripheral region.

The average etching non-uniformity u_{etch} depends on an etch-rate gradient defined between the center and the edge of the surface layer or between the central region and the peripheral region. This gradient is dependent on the flow rate of the etching solution in step c). It may also be modulated by dispensing a solution on the back side of the SOI substrate during all or part of step c); such dispensing may in particular modify the temperature of the substrate locally. Lastly, the etch-rate gradient depends on the temperature applied in step c).

The dispensing of step c) is carried out at a temperature between 20°C and 80°C, and for example at 65°C, for a given time, called the non-uniform etching time t_{nu} . The non-uniform etching time t_{nu} may vary from a few seconds to a few hundred seconds; in practice, it is less than 300 s, 250 s, or even 200 s, to meet the requirements of industrial efficiency.

Step d) corresponds to carrying out an etch on the front side of the surface layer, this involving dispensing a silicon-etching solution (for example, SC1, TMAH, HF/H₂O₂, HF/O₃, HF/HNO₃ + CH₃COOH, KOH, etc.)

with a sweeping movement from the edge to the center of the surface layer and back again; this sweeping ensures the etching has a certain uniformity over the entire surface of the layer.

The dispensing of step d) is carried out at a temperature between 20°C and 80°C, and for example at 65°C, for a given time, called the uniform etching time t_u . The uniform etching time t_u may vary from a few seconds to a few hundred seconds; in practice, it is less than 400 s, or even 300 s, also for reasons of industrial efficiency.

The proportions (volume ratios) of ammonium hydroxide (NH_4OH), hydrogen peroxide (H_2O_2) and deionized water of the SC1 when used as silicon-etching solution in step c) and in step d), may be chosen from 1/1/40 to 1/1/10, for example. The dispensing flow rate is typically between 1 and 2 liters per minute.

In the process of the invention, the number of cycles n , the non-uniform etching time t_{nu} and the uniform etching time t_u are determined, before carrying out steps b), c) and d), on the basis of an empirical model relating them to an average etched thickness e_{etch} of the surface layer and to the average etching non-uniformity u_{etch} .

It will for example be possible to define that the central region (uniformly distributed around the center of the substrate) and peripheral region (concentric, encircling the central region) correspond to 30% and 70% of the area of the surface layer, respectively.

Thus, given the average thickness E_{mean} and thickness non-uniformity U of the surface layer, after step a), and given the target average thickness E_{target} and the target thickness non-uniformity (U_{target}) for the surface layer, it is possible to use this model to determine optimum values for the number of cycles n , the non-uniform etching time t_{nu} and the uniform etching time t_u .

It is advantageous to express, in the model, the average etched thickness e_{etch} and the average etching non-uniformity u_{etch} in a quadratic form, as a function of variables which are the number of cycles n , the non-uniform etching time t_{nu} and the uniform etching time t_u , such as presented below :

[Equ1]

$$\begin{aligned}
e_{etch}(n, t_{nu}, t_u) \\
= \alpha_0 + \alpha_1 \cdot n^2 + \alpha_2 \cdot t_{nu}^2 + \alpha_3 \cdot t_u^2 + \alpha_4 \cdot n \cdot t_{nu} + \alpha_5 \cdot n \cdot t_u + \alpha_6 \cdot t_{nu} \cdot t_u \\
+ \alpha_7 \cdot n + \alpha_8 \cdot t_{nu} + \alpha_9 \cdot t_u
\end{aligned}$$

[Equ2]

$$\begin{aligned}
u_{etch}(n, t_{nu}, t_u) \\
= \beta_0 + \beta_1 \cdot n^2 + \beta_2 \cdot t_{nu}^2 + \beta_3 \cdot t_u^2 + \beta_4 \cdot n \cdot t_{nu} + \beta_5 \cdot n \cdot t_u + \beta_6 \cdot t_{nu} \cdot t_u + \beta_7 \cdot n \\
+ \beta_8 \cdot t_{nu} + \beta_9 \cdot t_u
\end{aligned}$$

Compared to a linear form, the quadratic form makes it possible to determine the three variables with a good accuracy.

The coefficients α_1 to α_9 and β_1 to β_9 are determined empirically on the basis of a design of experiments and of experimental measurements.

A three-objective optimization model with lexicographic optimality is particularly well suited to successively determining each of the variables. The objectives may be defined as follows:

- (i) identifying a first set of solutions $S_n^+(t_{nu}, t_u)$ for the non-uniform etching time t_{nu} and the uniform etching time t_u , making it possible to achieve equality between the average etched thickness e_{etch} of surface layer and a target average thickness to etch e_{target} , for any number of cycles n , said target average thickness to etch e_{target} being defined as the difference between the target average thickness E_{target} of the surface layer and the average thickness E_{mean} measured in step a);
- (ii) restricting the set of solutions $S_n^+(t_{nu}, t_u)$ identified in (i), to a second set of solutions $S(t_{nu}, t_u)$ for the non-uniform etching time t_{nu} and the uniform etching time t_u , making it possible to minimize the difference between the average etching non-uniformity u_{etch} and a target average etching non-uniformity u_{target} , for any number of cycles n , the target average etching non-uniformity u_{target} being defined as the difference between a target thickness non-uniformity U_{target} for the surface layer and the thickness non-uniformity U measured in step a),
- (iii) selecting a recipe from the second set of solutions $S(t_{nu}, t_u)$ defined in (ii) making it possible to maximize the number of cycles (n).

The first objective (i) aims to solve the equation of the second degree Equ3, resulting from the equality between the average etched thickness e_{etch} of surface layer and a target average thickness to etch e_{target} , said target average thickness to etch e_{target} being defined as the difference between the target average

thickness E_{target} of the surface layer and the average thickness E_{mean} measured in step a). The equation Equ3 is expressed with the uniform etching time t_u (time applied in step d) as variable:

[Equ3]

$$\alpha_3 \cdot t_u^2 + (\alpha_5 \cdot n + \alpha_6 \cdot t_{nu} + \alpha_9) t_u + (\alpha_0 + \alpha_1 \cdot n^2 + \alpha_2 \cdot t_{nu}^2 + \alpha_4 \cdot n \cdot t_{nu} + \alpha_7 \cdot n + \alpha_8 \cdot t_{nu} - e_{\text{target}}) = 0$$

Since the uniform etching time t_u is necessarily positive, the solution of this equation is expressed as a function of the non-uniform etching time t_{nu} (step c) and of the number of cycles (step b) as follows:

[Equ4]

$$t_u = \frac{-(\alpha_5 \cdot n + \alpha_6 \cdot t_{nu} + \alpha_9) + \sqrt{\Delta_{t_u}(t_{nu}, n)}}{2\alpha_3}$$

with

[Equ5]

$$\Delta_{t_u}(t_{nu}, n) = (\alpha_5 \cdot n + \alpha_6 \cdot t_{nu} + \alpha_9)^2 - 4 \cdot \alpha_3 \cdot (\alpha_0 + \alpha_1 \cdot n^2 + \alpha_2 \cdot t_{nu}^2 + \alpha_4 \cdot n \cdot t_{nu} + \alpha_7 \cdot n + \alpha_8 \cdot t_{nu} - e_{\text{target}})$$

At this stage, it is therefore possible to define a first set S_n of possible solutions t_u (uniform etching time) and t_{nu} (non-uniform etching time), for each integer n (number of cycles):

[Equ6]

$$S_n = \left\{ \left(t_{nu}, t_u = \frac{-(\alpha_5 \cdot n + \alpha_6 \cdot t_{nu} + \alpha_9) + \sqrt{\Delta_{t_u}(t_{nu}, n)}}{2\alpha_3} \right), \forall t_{nu} \in [t_{nu}^{\min}, t_{nu}^{\max}] \right\}$$

The first set of possible solutions for t_u and t_{nu} are further filtered to include only positive values and to reflect the technical feasibility of the tool, namely an accuracy in the times of 1 s, thus giving the following set of solutions S_n^+ at the end of the first step (first objective):

[Equ7]

$$S_n^+ = \{(t_{nu}, t_u), t_{nu} \geq 0, t_u \geq 0, \forall (t_{nu}, t_u) \in S_n\}$$

The second objective aims to minimize the difference between the average etching non-uniformity u_{etch} expressed in Equ2, and the target average etching non-uniformity u_{target} , defined as the difference

between a target thickness non-uniformity U_{target} for the surface layer and the thickness non-uniformity U measured in step a).

Starting with the solutions of the set S_n^+ retained in the first step, only recipes r_n making it possible to minimize the error in the etching non-uniformity u_{etch} are retained:

[Equ8]

$$r_n = \underset{(t_{nu}, t_u) \in S_n^+}{\text{argmin}} (|u_{\text{etch}}(n, t_{nu}, t_u) - u_{\text{target}}|)$$

The second set of solutions S at the end of the second step (second objective) is therefore expressed as:

[Equ9]

$$S = \{r_n, \forall n \in [0 \dots N]\}$$

The third objective aims to minimize the cost of the process, this being equivalent to maximizing the number of cycles n of step b) of the process, because step b) is the most efficient in terms of thinning.

The recipe among the solutions of the second set of solutions S having the highest number of cycles is therefore selected.

The trend curve Av in figure 2a illustrates the initial non-uniformity (i.e. before the application of the process according to the invention) of surface layers of 25 SOI substrates. In particular, the deviations in thickness with respect to the average thickness, at any measured point i , on the 25 surface layers, are compiled in figure 2a: an excess central thickness (radius 0) of 0.5 nm on average greater than the edge thickness will be noted.

The trend curve Ap of figure 2a illustrates the final non-uniformity of the same 25 surface layers, after implementation of steps b), c), and d) of the process according to the invention. The deviations in thickness with respect to the average thickness, at any measured point i , on the 25 surface layers, are compiled and it may be seen that the final non-uniformity is better, having a deviation of less than 0.2 nm on average between center and edge. The vast majority of the measured points meet the requirement in respect of the target thickness non-uniformity U_{target} of ± 0.4 nm.

In this example, the average thickness was evaluated based on 625 measurement points i . As may be seen in the stacked maps of the surface layers of the 25 SOI substrates (figure 2b), the thickness non-uniformity profile is modified after implementation of the thinning process according to the invention, and makes it possible to eliminate the excess central thickness and improve the overall uniformity of the surface layers.

Needless to say, the invention is not limited to the described embodiments and examples, and variants of embodiment may be applied thereto without departing from the scope of the invention as defined by the claims.

CLAIMS

1. A process for thinning a surface layer of an SOI substrate, comprising:
 - a) a step of measuring the thickness of the surface layer, to obtain an average thickness (E_{mean}) and a thickness non-uniformity (U) of said layer,
 - then the following steps, which are performed in a single-wafer chemical processing tool and during which the SOI substrate is rotated:
 - b) applying n cycles, with n a integer greater than or equal to 1, of oxidation and etching, to a front side of the surface layer, each cycle involving dispensing ozonated water then dispensing hydrofluoric acid,
 - c) carrying out a non-uniform etch on the front side of the surface layer, this involving dispensing a silicon-etching solution at a temperature between 20°C and 80°C, in a central region of the surface layer, for a given time, called the non-uniform etching time (t_{nu}),
 - d) carrying out a uniform etch on the front side of the surface layer, this involving dispensing a silicon-etching solution with a sweeping movement from the edge to the center of the surface layer and back again, at a temperature between 20°C and 80°C, for a given time, called the uniform etching time (t_{u}),

wherein, given the average thickness (E_{mean}) and the thickness non-uniformity (U) of the surface layer, the number of cycles (n), the non-uniform etching time (t_{nu}) and the uniform etching time (t_{u}) are determined, before carrying out steps b), c) and d), on the basis of a model relating them to an average etched thickness (e_{etch}) of the surface layer and to an average etching non-uniformity (u_{etch}) defined as the difference between an average etched thickness in a central region of the surface layer and an average etched thickness in a peripheral region of the surface layer.
2. The thinning process as claimed in the preceding claim, wherein the average etching non-uniformity (u_{etch}) is positive.
3. The thinning process as claimed in either of the preceding claims, wherein the central region and peripheral region correspond to 30% and 70% of the area of the surface layer, respectively.
4. The thinning process as claimed in one of the preceding claims, wherein the average etched thickness (e_{etch}) and the average etching non-uniformity (u_{etch}) are each expressed in a quadratic form,

as a function of variables which are the number of cycles (n), the non-uniform etching time (t_{nu}) and the uniform etching time (t_u).

5. The thinning process as claimed in the preceding claim, wherein the model for determining the number (n) of cycles, the non-uniform etching time (t_{nu}) and the uniform etching time (t_u) is a three-objective optimization model with lexicographic optimality.

6. The thinning process as claimed in the preceding claim, wherein said objectives are:

(i) identifying a first set of solutions ($S_n^+(t_{nu}, t_u)$) for the non-uniform etching time (t_{nu}) and the uniform etching time (t_u), making it possible to achieve equality between the average etched thickness (e_{etch}) of surface layer and a target average thickness to etch (e_{target}), for any number of cycles (n), said target average thickness to etch (e_{target}) being defined as the difference between the target average thickness (E_{target}) of the surface layer and the average thickness (E_{mean}) measured in step a);

(ii) restricting the first set of solutions ($S_n^+(t_{nu}, t_u)$) identified in (i), to a second set of solutions ($S(t_{nu}, t_u)$) for the non-uniform etching time (t_{nu}) and the uniform etching time (t_u), making it possible to minimize the difference between the average etching non-uniformity (u_{etch}) and a target average etching non-uniformity (u_{target}), for any number of cycles (n), the target average etching non-uniformity (u_{target}) being defined as the difference between a target thickness non-uniformity (U_{target}) for the surface layer and the thickness non-uniformity (U) measured in step a),

(iii) selecting a recipe from the second set of solutions ($S(t_{nu}, t_u)$) defined in (ii) making it possible to maximize the number of cycles (n).

7. The thinning process as claimed in one of the preceding claims, wherein steps b), c) and d) are performed in order.

8. The thinning process as claimed in one of the preceding claims, wherein the temperature in steps c) and d) is set to 65°C.

9. The thinning process as claimed in one of the preceding claims, wherein, in step c), the silicon-etching solution is dispensed solely at the center, or with a sweeping movement from the center to 50% of the radius of the surface layer and back again.

10. The thinning process as claimed in one of the preceding claims, wherein the average etching non-uniformity (U_{etch}) depends on an etch-rate gradient defined between the center and the edge of the surface layer, said gradient being dependent:

- on a flow rate of the silicon-etching solution in step c), and/or
- on whether a solution is dispensed on the back side of the SOI substrate during all or part of step c), and/or
- on the temperature applied in step c).

11. Thinning process according to one of the preceding claims, wherein the silicon-etching solution in step c) and/or step d) is SC1.