

Method for depositing an epitaxial layer on a substrate wafer

The invention relates to a method for depositing an epitaxial layer on a substrate
5 wafer.

Prior art / problems

For demanding applications in the electronics industry, epitaxially coated
semiconductor wafers are required, in particular substrate wafers made of single-
10 crystal silicon which are epitaxially coated with a layer of silicon.

A commonly used method for depositing the layer is chemical vapor phase deposition.
The material for the layer is provided by process gas, which is passed over the side of
the substrate wafer to be coated at temperatures at which a precursor compound
15 contained in the process gas and containing the material is chemically cleaved. The
substrate wafer is located in the pocket of a susceptor during the deposition of the
layer, while at the same time being surrounded by an annular boundary of the
susceptor. The process is usually carried out in a device which is designed as a single
wafer reactor. Such a single-wafer reactor is described in EP 0 870 852 A1, for
20 example.

In order to grow the epitaxial layer as uniform as possible on the substrate wafer, it is
particularly important that the substrate wafer is centered in the pocket with respect to
the boundary.
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In US 2010 0216261 A1 it is proposed to monitor the correct position of the substrate
wafer on the receptor by means of a camera system.

WO17 135 604 A1 proposes to measure a thickness characteristic value in the edge
30 region after the deposited epitaxial layer and to modify certain process parameters for
subsequent deposition processes depending on the measurement result.

WO 14 103 657 A1 and JP2015 201 599 A disclose methods in which an eccentricity is calculated based on the distribution of thickness characteristic values in the edge region of the semiconductor wafer with an epitaxially deposited layer, in order to correct the position of a subsequent substrate wafer on the susceptor as a function of this eccentricity.

US2009 252 942 A1 and JP2002 043 230 A propose to measure the flatness of the substrate wafer before the deposition of the epitaxial layer and to modify certain process parameters during the deposition process in such a way that the coating of the substrate wafer reduces an edge roll-off.

However, this procedure does not prevent thickness differences in the edge region of the epitaxially coated substrate wafer if the substrate wafer itself already has thickness differences in the edge region.

The object of the invention is to provide a solution to the problem that allows the thickness of the epitaxial layer to be adjusted according to the edge roll-off of the substrate wafer.

The object of the invention is achieved by a method for depositing an epitaxial layer on a substrate wafer from a vapor phase, comprising measuring an edge geometry of the substrate wafer that assigns a thickness characteristic value to an edge of the substrate wafer as a function of edge positions; placing the substrate wafer in a pocket of a susceptor of a device for depositing the epitaxial layer, the pocket being surrounded by a boundary with a circular circumference; heating the substrate wafer; and passing process gas over the substrate wafer; which comprises placing the substrate wafer in the pocket such that the distance from the substrate wafer to the boundary of the pocket is smaller at edge positions with the thickness characteristic value of a thicker edge than at edge positions with the thickness characteristic value of a thinner edge.

The invention is based on the finding that the centered placement of the substrate wafer in the pocket is based on the assumption that the substrate wafer has a uniform edge geometry. In practice, however, this is rarely the case, because machining steps such as grinding and polishing are not able to create a substrate wafer with a
5 completely uniform edge thickness. The method according to the invention is able to deliver a more uniform edge geometry of an epitaxially coated semiconductor wafer compared to the uncoated substrate wafer, in particular if the substrate wafer has a comparatively low edge thickness in one edge section and a comparatively high edge thickness in the opposite edge section. Nevertheless, a homogenization of the edge
10 thickness can also be achieved if, for example, only one edge section with comparatively low edge thickness is present.

Firstly, the edge geometry of the substrate wafer is measured such that it is available in the form of a thickness characteristic value. Preferably, an outermost edge portion
15 with a radial length of 1 mm or 2 mm is excluded from the measurement as an edge exclusion. In principle, any measured value that allows a statement to be made about the relative thickness at two different sections in the edge region of the substrate wafer can be considered as a thickness parameter. For example, suitable parameters for the thickness characteristic value are the ZDD (Z double derivative) of the front
20 face, which describes the curvature of the edge roll-off and is defined in the SEMI standard M68-0720, or the ESFQR, which quantifies the flatness of sectors (sites) in the edge region and is defined in the SEMI standard M67-0720. The remainder of the description uses ESFQR to represent the thickness characteristic.

25 The method according to the invention provides for measuring the edge geometry of a substrate wafer before it is coated with an epitaxial layer. For example, a map is provided that assigns an ESFQR value to each sector, thus indicating a thickness profile of the substrate wafer along its circumference. Substrate wafers with a wedge-like cross-sectional shape, or those that are thinner on one edge than on others, are
30 particularly suitable. An edge section means an edge region that extends over a distance of up to 50% of the circumference, preferably 7% to 42% of the circumference in the circumferential direction. A substrate wafer with a wedge-like

shape has a thicker edge section and a thinner edge section which are opposite each other, i.e. have the maximum possible distance from each other.

A correlation function is created for the deposition chamber used for coating the substrate wafer, a single-wafer reactor. This function assigns a thickness characteristic value to a displacement vector. The displacement vector indicates the direction and magnitude by which the thicker edge section of the substrate wafer must be offset from the centered position to be placed in the pocket of the susceptor, so that more material is deposited on the opposite, thinner edge section than on the thicker edge section when depositing the epitaxial layer. Accordingly, after the deposition in the thinner edge section of the substrate wafer, the thickness characteristic value is greater by the assigned thickness characteristic value than it would be after the deposition of an epitaxial layer during which the substrate wafer is centered in the pocket of the susceptor. The displacement vector thus represents an eccentricity of the position of the center point of the substrate wafer placed on the susceptor compared to the position that the center point would have if the substrate wafer were centered in the pocket of the susceptor. The correlation function is determined by experiments prior to coating the substrate wafer, by determining which eccentricity results in which change of the thickness characteristic value.

The placement of the substrate wafer in the pocket of the susceptor is preferably carried out by a robot which performs this task as specified by the correlation function. Alternatively or in addition, the robot can be configured as a self-learning system which uses the measured geometry data of the substrate wafers and the resulting epitaxially coated semiconductor wafers to determine and implement the necessary eccentricity for the coating of subsequent substrate wafers. In addition, it is preferable to monitor the placement of the substrate wafer on the susceptor and its position in the pocket of the susceptor by means of a camera system.

The substrate wafer and the epitaxial layer deposited on it preferably consist essentially of semiconductor material, for example single-crystal silicon. The substrate wafer preferably has a diameter of at least 200 mm, particularly preferably at least 300 mm. The epitaxial layer preferably has a thickness of 1 μm to 20 μm .

The invention is described in further detail below with reference to drawings.

Brief Description of The Drawings

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Fig. 1 shows the effect of the invention qualitatively.

Fig. 2 shows a substrate wafer placed according to the invention in the pocket of the susceptor.

10 **Fig. 3** shows a correlation function that assigns an expected change in a thickness characteristic value to an eccentricity E.

Fig. 4 shows the deviation of the thickness of a substrate wafer from a target thickness along its diameter

15 **Fig. 5** shows the deviation of the thickness of the epitaxially coated substrate wafer according to Fig. 4 from a target thickness along the diameter of the epitaxially coated substrate wafer

Fig. 6 shows the deviation of the thickness of the epitaxial layer of the coated substrate wafer according to Fig. 5 from a target thickness along the diameter of the epitaxial layer.

20 **Fig. 7** shows the curve of the deviation of the thickness characteristic value from a target value along the circumference of a substrate wafer before and after the deposition of an epitaxial layer.

List of reference signs used

- 25 **1** substrate wafer
 2 epitaxial layer
 3 susceptor
 4 pocket
 5 thick edge section of the substrate wafer
 30 **6** thin edge section of the substrate wafer
 7 outer boundary of the pocket
 8 map
 E eccentricity

ESFQR ESFQR value

Δ **ESFQR** difference between the ESFQR value and the target value

Δt difference of thickness t from target thickness

d diameter

5 **WP** edge position

Detailed description of exemplary embodiments according to the invention

Fig.1 shows a sectional view (vertical section) of a substrate wafer 1, which is deposited in the pocket 4 of a susceptor 3 and has an edge section 5 that is comparatively thick and an edge section 6 opposite thereto that is comparatively thin. The substrate wafer 1 is not located centrally in the pocket 4, but eccentrically, so that the thicker edge section 5 is a shorter distance from a boundary 7 of the pocket than the thinner edge section 6. The consequence of this configuration is that where the distance is smaller, the rate of growth of material during the deposition of the epitaxial layer is lower than where the distance is greater.

The lower part of Fig. 1 shows the situation after the deposition of the epitaxial layer 2. The substrate wafer 1 has become a substrate wafer with a deposited epitaxial layer, wherein the epitaxial layer 2 is thinner in the region of the edge section with a shorter distance to the boundary 4 than in the region of the edge section with a greater distance to the boundary 4. Considering the thickness of the substrate wafer with a deposited epitaxial layer 2 and comparing it with the thickness of the substrate wafer 1, it is found that the thickness of the epitaxially coated substrate wafer in its edge region is more uniform than the thickness of the substrate wafer 1. The thickness differences in the edge region are more pronounced in the case of the substrate wafer 1 than in the case of the epitaxially coated substrate wafer.

Fig. 2 shows a plan view of a substrate wafer placed according to the invention in the pocket of the susceptor. The substrate wafer 1 is not located centrally in the pocket of the susceptor. The center of the substrate wafer is shifted from the center of the pocket in accordance with the eccentricity E , such that the thicker edge section 6 is a shorter distance from the outer boundary 7 of the pocket than the thinner edge section 6. The direction and magnitude of the eccentricity E depend on a measurement of the edge geometry of the substrate wafer, for example, by measuring the flatness in the form of the ESFQR value in 5°-wide edge segments. The result of the measurement is

indicated qualitatively by the depicted map 8 and identifies the thicker edge section 5 highlighted with "+" symbols and the thinner edge section 6 highlighted with "-" symbols.

- 5 The selected eccentricity E is based on a correlation function which is determined by preliminary tests for the deposition device to be used. The tests examine what change in the thickness characteristic value is to be expected when the substrate wafer is placed in the pocket of the susceptor with a certain eccentricity E . In the selected example, the correlation function according to Fig. 3 indicates the difference ΔESFQR in the ESFQR value obtained in the thinner edge section after the deposition when the substrate wafer is not placed in the pocket of the susceptor in a central position, but with the corresponding eccentricity E . The correlation function according to Fig. 3 thus suggests that after the deposition of the epitaxial layer, the ESFQR value in the sectors of the thinner edge section will be increased by approximately 2 nm if the substrate wafer was not placed in the pocket of the susceptor centrally, but rather with an eccentricity of 100 μm before the deposition.

- Fig. 4, Fig. 5 and Fig. 6 respectively show the curve of the deviation of a thickness from a target thickness of a single-crystal silicon substrate wafer before (Fig. 4) and after (Fig. 5) the deposition of an epitaxial layer, and the deviation of the thickness of the epitaxial layer (Fig. 6) from a target thickness. According to Fig. 4, the substrate wafer had significantly different edge thicknesses, with a thinner edge section in the region of 0 mm and a thicker edge section in the region of 300 mm. After the deposition of the epitaxial layer according to the present invention, the difference in the edge thicknesses in these edge sections was almost compensated (Fig. 5). The curve of the thickness deviation of the epitaxial layer according to Fig. 6 shows that due to the application of the invention, the epitaxial layer is thicker at the edge position corresponding to the thinner edge section of the substrate wafer and is thinner at the edge position corresponding to the thicker edge section of the substrate wafer. The eccentric position of the substrate wafer has caused different amounts of material to be deposited at the edge sections under consideration.

- The approach according to the invention improves the edge geometry, even if it is considered over the entire circumference. Fig. 7 shows the edge geometry of a substrate wafer in the form of smoothed curves before (curve A) and after (curve B)

the deposition of an epitaxial layer, in this case in the form of the ESFQR value as a function of the edge position WP. The curves are based on 72 measurement points, each of which describes the ESFQR value of a sector with a width of 5° and a radial length of 35 mm, allowing for an edge exclusion of 1 mm.

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The above description of example embodiments is to be understood as exemplary. The resulting disclosure enables, on the one hand, the person skilled in the art to understand the present invention and its associated advantages, and on the other hand, also encompasses obvious variations and modifications of the described structures and methods within the understanding of the person skilled in the art. Therefore, all such variations and modifications as well as their equivalents are intended to be covered by the scope of protection of the claims.

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Patent claims

1. A method for depositing an epitaxial layer on a substrate wafer from a vapor phase, comprising
 - 5 measuring an edge geometry of the substrate wafer that assigns a thickness characteristic value to an edge of the substrate wafer as a function of edge positions; placing the substrate wafer in a pocket of a susceptor of a device for depositing the epitaxial layer, the pocket being surrounded by a boundary with a circular circumference;
 - 10 heating the substrate wafer; and passing process gas over the substrate wafer; which comprises placing the substrate wafer in the pocket such that the distance from the substrate wafer to the boundary of the pocket is smaller at edge positions with the thickness characteristic value of a thicker edge than at edge positions with the thickness
 - 15 characteristic value of a thinner edge.
2. The method as claimed in claim 1, which comprises measuring the ESFQR or the ZDD as the thickness characteristic value.
- 20 3. The method as claimed in claim 1 or claim 2, which comprises placing the substrate wafer by means of a robot.
4. The method as claimed in any one of claims 1 to 3, which comprises
- 25 monitoring the position of the substrate wafer in the pocket by means of a camera system.
5. The method as claimed in any one of claims 1 to 4, which comprises depositing an epitaxial layer of silicon on a single-crystal silicon wafer.