

Device and method for drying waferlike substrates

Technical Field

Subjects of the present invention are a device for drying waferlike substrates and a
5 method for drying waferlike substrates.

Prior Art

Wafers of semiconductor material, examples being wafers of monocrystalline silicon (silicon wafers), are produced in a multiplicity of process steps which include drawing
10 a single-crystal ingot from a melt, sawing the crystal into wafers, grinding, edge rounding, polishing, and chemically cleaning the wafers. The chemical cleaning removes impurities and passivates the surfaces of the wafers. One form of chemical cleaning is wet cleaning, which necessitates subsequent drying of the wafers.

In the chemical cleaning operation, the waferlike substrates are immersed for some time into one or more baths of a liquid and then withdrawn at a slow rate such that as
15 few liquid remnants as possible remain adhering to the substrates. The reason for this is that the liquid remnants adhering to the waferlike substrates may constitute a source of impurities and significantly affect the quality of the surface of the waferlike substrate, especially in the edge region. Liquid remnants which initially adhere between the wafer holder and a substrate may spread onto the side faces of the
20 substrate and leave particles on the substrate after drying. Since the liquid remnants may contain compounds of low volatility such as metal particles, the impurities are left on the wafer surface even after the evaporation of the liquid.

To dry waferlike substrates immersed in liquid, one appropriate method entails transferring the substrates, in the course of the method, from the liquid into a gas
25 space containing vapor which does not condense on the substrates and which lowers the surface tension of the liquid remnants adhering to the substrate. The method and the physical effect it utilizes are described in EP 0 385 536 A1, as is a device suitable for performing such a method.

Further devices and methods for improving the cleaning quality in respect of remanent particles on the waferlike substrate are also described in documents DE 10 2014 207 266 A1, EP 3 840 021 A1, EP 3 840 022 A1, and EP 3 840 023 A1. When these devices and methods are employed, however, there are always still particles left over
5 that diminish the quality of the waferlike substrates. An object of the present invention is to further improve the drying methods and devices described in the prior art and accordingly to lower the number of particles which are left on the dried substrates.

Technical Object of the Invention and its Solution

It is therefore an objective of the present invention to provide a device and a method
10 for drying waferlike substrates that make it possible for the liquid remnants, and hence the particles contained in the liquid that adhere to the waferlike substrates, to be removed more effectively and efficiently.

The object here is achieved in accordance with the invention by a device for drying waferlike substrates in accordance with the first aspect of the present invention.
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This device comprises an element having a horizontal principal extent direction and, transverse to the principal extent direction, a cross-sectional profile which tapers upward in vertical direction,
wherein the element at its top side has a plurality of support positions which are
20 suitable for supporting waferlike substrates,
the plurality of support positions are arranged along the principal extent direction,
the plurality of support positions are bordered by faces of the element that fall away starting from the support positions,
at least some of the faces of the element that border the support positions and fall
25 away have an upper portion and a lower portion, and
the upper portion is more hydrophilic than the lower portion.

It has surprisingly been established that the configuration of the faces bordering the support positions and falling away starting from the support positions with an upper,
30 more hydrophilic portion and a lower, more hydrophobic portion allows liquid remnants

to be removed more rapidly and efficiently and hence allows the level of the impurities on the surface of a waferlike substrate to be further reduced.

In accordance with the second aspect, the present invention is directed to a method for drying waferlike substrates immersed in a liquid. The method comprises the following steps:

positioning the waferlike substrates immersed in the liquid on the device according to the first aspect of the present invention; and

transferring the waferlike substrates with the device from the liquid into a gas space containing a vapor which does not condense on the waferlike substrates and which lowers the surface tension of liquid remnants adhering to the waferlike substrates.

In this method, liquid remnants between the waferlike substrates and the device supporting the wafers can run off via the downwardly inclined faces of the element that border the support positions and so be removed. It is therefore possible for there to be no active removal of the liquid remnants between the waferlike substrates and the wafer holder.

Because the upper portion is more hydrophilic, aqueous liquid remnants or liquid remnants with polar solvent fractions which have collected at the lower edge of the waferlike substrates are more easily able at the support positions to transition to the bordering, downwardly falling faces of the element. Because the lower portion of the faces is more hydrophobic, the liquid remnants are more easily able to be taken off from the faces and returned to the liquid bath. This enables efficient removal of liquid remnants from the waferlike substrates. As a result, the number of particles remaining on the waferlike substrates after drying can be reduced. Furthermore, the improved run-off of the liquid remnants when the substrates are withdrawn from the bath further reduces the net withdrawal of cleaning liquid, so improving the economics of the chemical cleaning. Furthermore, the improved run-off of the liquid remnants allows the amount of liquid evaporated from the substrate surface to be reduced, so leading to an improvement of the atmosphere in the clean room.

Brief Description of the Figures

Fig. 1 shows an element (1) of a device of the invention for drying waferlike substrates. The element has a cross-sectional profile (3) transverse to the principal extent direction (2) that tapers upward in vertical direction. On its top side, the element has an edge profile (6) which is marked by a zigzag shape and runs along the principal extent direction (2). The individual edges (4) abutting one another in principal extent direction form lower-lying kinks (5) which serve as support positions for the waferlike substrates.

Fig. 2a shows the cross-sectional profile and **Fig. 2b** the longitudinal profile of the element (1) represented in **Fig. 1**.

Fig. 3 shows the measurement results in the determination of the contact angle α of a water drop on faces of the element of the device of the invention that border the support positions and fall away, as a function of the distance s from the support position.

Detailed Description of the Invention

Waferlike substrates in the sense of the present invention are, for example, wafers of semiconductor material, preferably wafers of monocrystalline silicon which is optionally doped. The waferlike substrates preferably have a diameter of 150 to 450 mm, more preferably 200 mm or 300 mm, most preferably 300 mm.

The device of the invention for drying waferlike substrates according to the first aspect of the present invention comprises an element having a horizontal principal extent direction and, transverse to the principal extent direction, a cross-sectional profile which tapers upward in vertical direction. The cross-sectional profile is preferably symmetrical in relation to a vertical axis of symmetry. The cross-sectional profile of the element preferably has an acute angle in its upper part. In this case, the vertex of the acute angle, as the highest point of the cross-sectional profile, forms the support point for supporting the waferlike substrate.

The element preferably tapers in vertical direction upward to an edge or an edge profile. The edge profile consists of a plurality of mutually abutting edges which lie in the same plane, preferably in a plane perpendicular to the cross-sectional profile. At each edge of the edge profile, two faces which fall away starting from the edge abut

one another. The points at which pairs of edges of the edge profile abut one another are referred to below as kinks. For example, the edge profile may be a zigzag profile. This edge profile runs preferably along the principal extent direction. This means that the edge profile and the principal extent direction lie in the same plane, which is probably arranged perpendicular to the cross-sectional area.

The element has a plurality of support positions at its top side which are suitable for supporting waferlike substrates, with the plurality of support positions being arranged along the principal extent direction and bordering faces of the element that fall away starting from the support positions. The support positions are formed preferably by one or more edges at the top side of the element, with two falling faces abutting one another at each edge. The support positions are formed preferably by edges at which faces of the element that fall away starting from the edge abut one another. At least some of the falling faces bordering the support positions have an upper portion and a lower portion, with the upper portion being more hydrophilic than the lower portion. Preferably all of the falling faces bordering the support positions have an upper portion and a lower portion, with the upper portion being more hydrophilic than the lower portion.

If the element tapers upward to an edge in vertical direction – if, for example, the element is configured as a wedge-shaped element – the upward-pointing edge serves to support the waferlike substrates. In this case, the one upward-pointing edge provides a plurality of support positions. If the element tapers upward to an edge profile in vertical direction, the support positions are formed preferably by kinks in the edge profile, more preferably by the downward-pointing kinks. If the edge profile is a zigzag profile, the kinks serving as support positions for the waferlike substrates are preferably those starting from which two edges run upward. A support position may therefore also be formed by two edges which, at the top side of the element, run along the principal extent direction, border one another, and have a different inclination in relation to the horizontal.

The support position may also be configured as a recess at the top side of the element transverse to the principal extent direction. The recess may reduce or entirely prevent the slipping or tipping of the waferlike substrate, supported at the support position, along the principal extent direction, especially if the waferlike substrates are

arranged transverse to the principal extent direction. The extent of the individual recesses along the principal extent direction here exceeds the thickness of the waferlike substrates, allowing these substrates to be inserted into the recesses and supported by them transverse to the principal extent direction. The recesses run
5 preferably in transverse direction, i.e., perpendicular to the principal extent direction and perpendicular to the vertical. The recesses here may be cuboidal, beveled, V-shaped, or rounded at their bottom side.

The support positions are bordered by faces of the element that fall away downward
10 starting from the support positions. At least some of these faces have, respectively, an upper portion and a lower portion, the upper portion being more hydrophilic than the lower portion. Each support position, which is formed preferably by one or more edges, is preferably bordered by at least two downwardly falling faces having, respectively, an upper portion and a lower portion, with the upper portion being more
15 hydrophilic than the lower portion. The at least two downwardly falling faces are preferably arranged at opposite sides, starting from the respective support position. A downwardly falling face in the sense of the present invention may have, for example, an inclination of more than 10° and less than 80° in relation to the vertical. A falling face in the sense of the present invention may also be curved or vaulted. Falling in
20 the sense of the present invention means that the part of the face bordering the support position is further upward than a part of the face more remote from the support position. Accordingly, with the assistance of gravity, liquid remnants may be taken off via the falling faces from the substrates supported on the support positions.

25 The upper portion preferably directly borders a support position of the element. Because the upper portion is more hydrophilic than the lower portion, aqueous liquid remnants, in the form of drops, for example, are more easily able to be transferred from the lower edge region of the waferlike substrates, supported by the element, onto the element and so removed from the substrate. The surface in the upper portion of
30 the downwardly falling faces of the element that border the support positions is preferably more hydrophilic than the surface of the waferlike substrate. In this case, aqueous liquid remnants can flow off from the substrate to the upper portion. Furthermore, in this case, a water bridge to the more hydrophilic element, or to the more hydrophilic upper portion of the face bordering the support position, this bridge
35 forming on separation of substrate and element, is drawn and therefore removed from

the substrate. As a result of gravity, these liquid remnants then flow from the upper to the lower portion of the falling faces of the element. Because the surface of the lower portion is more hydrophobic, it is less readily wettable, and so the liquid remnants continue to flow off and can therefore be transferred from the element back into the liquid bath or another collecting container.

The hydrophilicity is a measure of the wettability. A more hydrophilic surface therefore has a better wettability in respect of water. In the present invention, the contact angle α of a drop of a liquid at a defined site on a surface is employed as a measure of the hydrophilicity of the surface at this site. Preference is given to employing the contact angle α of a water drop, more preferably of a drop of deionized water, for the purpose of determining the hydrophilicity. A more hydrophilic surface in the sense of the present invention is a surface on which a water drop has a smaller contact angle α , in comparison to a different surface. A more hydrophobic surface in the sense of the present invention is a surface on which a water drop has a larger contact angle α , in comparison to a different surface. A more hydrophilic surface in the sense of the present invention is preferably characterized in that a water drop, preferably a drop of deionized water, has a contact angle α thereon of not more than 45° , more preferably a contact angle α of not more than 40° , most preferably not more than 30° . In one embodiment of the present invention, the more hydrophilic, upper portion of the faces bordering the support positions is configured such that a water drop, preferably a drop of deionized water, has a contact angle thereon of not less than 20° and not more than 30° . Accordingly, a more hydrophobic surface in the sense of the present invention is characterized in that a water drop, preferably a drop of deionized water, has a contact angle α thereon of not less than 50° , preferably not less than 60° .

The contact angle α of a drop of a liquid at the downwardly falling faces of the element that border the support positions is preferably a monotonic function of the distance s from the support position. With particular preference, the contact angle α of a water drop at the downwardly falling faces of the element that border the support positions is a monotonic rising function of the distance s from the support position. The contact angle α of a water drop on one of the downwardly falling faces of the element that border the support positions therefore increases or remains the same as the distance s goes up.

The contact angle α may be determined according to the following method:

- (i) wetting at least one site on a face, preferably at least one site on the upper portion and at least one site on the lower portion of a falling face of the element, with respective drops of a liquid;
- 5 (ii) recording an image of each drop, preferably a shadow image;
- (iii) determining the contour of the respective drop from the respective image, preferably the shadow image, by means of suitable software; and
- (iv) determining the contact angle between the surface and the respective drop from the determined contour of the respective drop.

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In step (i), the site to be investigated on the surface is wetted with a drop of a liquid, preferably with a water drop, more preferably with a drop of deionized water. In step (ii), an image of the drop, preferably a shadow image, is recorded by means of a camera. In step (iii), the contour of the drop is then determined from the image by means of suitable software. Here, a contour recognition may be performed by means of a
 15 grayscale analysis of the image, and subsequently a geometric model describing the drop contour may be identified. The geometric model describing the drop contour may be identified, for example, by fitting. The contact angle is obtained from the angle between the drop contour function ascertained and the surface of the site investigated, the projection of which in the drop image may be referred to as a baseline. Geometric
 20 models describing the drop contour that may be employed are, for example, a circle, conic section, ellipse or polynomial.

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The element may consist of metal, ceramic or plastic. The element preferably consists of a thermoplastic, most preferably of a thermoplastic possessing high-temperature stability. The high-temperature-stable thermoplastic may for example be a polyaryletherketone, preferably polyetheretherketone (PEEK), which has high chemical stability, wear resistance, and good sliding properties. The element of the device of the invention for drying waferlike substrates therefore consists preferably of
 30 PEEK.

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The hydrophilicity of a surface may be modified by physical methods, such as plasma treatment, or by chemical methods, such as by surface reactions, coating or incorporation of a chemical compound.

The hydrophilicity of a surface of a thermoplastic such as PEEK may be increased, for instance, by direct gas phase fluorination. For example, the surface of an element composed of PEEK may be treated by treatment with a gas mixture of fluorine and air, where the gas mixture may have a fluorine content of 5 mol% fluorine.

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Surfaces may also be hydrophilized using a laser. For instance, surfaces of metallic materials or ceramics can be cleaned by means of a laser in an air atmosphere, leading to a more hydrophilic surface. Hydrophilization of a surface may also be accomplished using a laser and a silicating liquid, so as to clean and additionally functionalize the surface. As a result of this, the treated surface becomes even more hydrophilic. Laser silicating may be performed in an immersion bath. The local resolution may be varied according to the optical system employed, with the diameter of the smallest possible laser spot being less than 100 μm . The use of a laser means that cleaning and, where appropriate, silicating take place with very high local resolution. As a result, this method is especially suitable for producing surfaces having different portions with differing levels of hydrophilicity.

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In accordance with the second aspect, the present invention is directed to a method for drying waferlike substrates immersed in a liquid. The method comprises the following steps:

positioning the waferlike substrates immersed in the liquid on the device according to the first aspect of the present invention; and
transferring the waferlike substrates with the device from the liquid into a gas space containing a vapor which does not condense on the waferlike substrates and which
lowers the surface tension of liquid remnants adhering to the waferlike substrates.

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In this method, liquid remnants between the waferlike substrates and the wafer holder are able to run off by way of the downwardly inclined faces of the element of the device that border the support positions, and so be removed. It is therefore possible for there to be no active removal of the liquid remnants between the waferlike substrates and the wafer holder.

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Vapor which does not condense on the substrates has a vapor pressure which is not saturated at the temperature of the bath and of the substrates, whereas a vapor which condenses on the substrates actually has such a saturated vapor pressure. The

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substrates may be treated in different liquid baths. If the cleaning bath contains water, preference is given to using the vapor of an organic solvent, preferably one or more compounds selected from alcohols, glycols, aldehydes, esters, ketones or tetrahydrofuran. The method of the invention may also be employed when the bath
5 contains other polar liquids, alcohols being examples. The substrates may then be contacted directly from the alcohol with the vapor of the organic solvent 1,1,1-trifluorotrchloroethane.

Because the upper portion is more hydrophilic, aqueous liquid remnants or liquid
10 remnants with polar solvent fractions which have collected at the lower edge of the waferlike substrates are able more easily to transition, at the support positions, to the bordering, downwardly falling faces of the element. As a result of the fact that the lower portion of the faces is more hydrophobic, the liquid remnants can more easily be taken off from the faces and returned to the liquid bath.

Description of a working example according to the invention and of a comparative example

In the working example, a device of the invention as represented in Fig. 1 was em-
20 ployed for drying 50 wafers of monocrystalline silicon having a diameter of 300 mm and a thickness of 750 μm . The element of the device tapered upward to an edge profile with a zigzag shape along the principal extent direction (see Fig. 2b). The element consisted of PEEK, with the upper portion of the faces bordering the edges of the edge profile having been treated with a gas mixture of 5 mol% fluorine and air as
25 purge gas. The falling faces of the element of the device therefore had an upper portion and a lower portion, the upper portion being more hydrophilic than the lower portion. The wafers, standing on the upper edge in transverse direction to the principal extent direction of the device, were transferred from a water-filled tank into a gas space containing isopropyl vapor.

30 In a comparative example, the device used was the same as in the working example, with the exception that the falling faces of the element of the device were not treated with fluorine. The procedure was otherwise exactly the same as in the working example.

The dried semiconductor wafers were investigated for the presence of particles in the region of the support position on the element. Comparison of the working example with the comparative example showed that the drying performed with the device of the invention and in accordance with the method of the invention, in the working example,
5 resulted in considerably fewer residues on the dried wafers.

What is claimed is:-

1. A device for drying waferlike substrates, comprising an element (1) having a horizontal principal extent direction (2) and, transverse to the principal extent direction (2), a cross-sectional profile (3) which tapers upward in vertical direction, wherein the element (1) at its top side has a plurality of support positions which are suitable for supporting waferlike substrates, the plurality of support positions are arranged along the principal extent direction (2), the plurality of support positions are bordered by faces of the element that fall away starting from the support positions, at least some of the faces of the element that border the support positions and fall away have an upper portion and a lower portion, and the upper portion is more hydrophilic than the lower portion.
2. The device for drying waferlike substrates as claimed in claim 1, wherein the contact angle α of a drop of a liquid on a defined site on a surface is employed as a measure of the hydrophilicity of this surface site.
3. The device for drying waferlike substrates as claimed in claim 1 or 2, wherein the contact angle α at the falling faces of the element that border the support positions may be described as a monotonically increasing function of the distance s from the support position.
4. The device for drying waferlike substrates as claimed in any of claims 1 to 3, wherein the contact angle α is determined according to the following method:
 - (i) wetting at least one site on the upper portion and at least one site on the lower portion with respective drops of a liquid;
 - (ii) recording an image of each drop;
 - (iii) determining the contour of the respective drop from the respective image by means of suitable software; and
 - (iv) determining the contact angle between the surface and the respective drop from the determined contour of the respective drop.
5. The device for drying waferlike substrates as claimed in any of claims 1 to 4, wherein the support positions are configured such that the waferlike substrates supported thereon are arranged transverse to the principal extent direction.

6. The device for drying waferlike substrates as claimed in any of claims 1 to 5, wherein the cross-sectional profile at the support positions has an acute angle in its upper part.
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7. The device for drying waferlike substrates as claimed in any of claims 1 to 6, wherein the element tapers in vertical direction upward to an edge or an edge profile.
8. The device for drying waferlike substrates as claimed in any of claims 1 to 7, wherein each support position is marked by a kink in the edge profile.
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9. The device for drying waferlike substrates as claimed in any of claims 1 to 8, wherein the support positions are configured such that the waferlike substrates supported thereon are inclined out of the vertical.
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10. The device for drying waferlike substrates as claimed in any of claims 1 to 9, wherein the element is embodied such that the waferlike substrates at the support positions lie on the highest point of the respective cross-sectional profile.
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11. A method for drying waferlike substrates immersed in a liquid, comprising positioning the waferlike substrates immersed in the liquid on the device as claimed in any of claims 1 to 10; and transferring the waferlike substrates with the device from the liquid into a gas space containing a vapor which does not condense on the waferlike substrates and which lowers the surface tension of liquid remnants adhering to the waferlike substrates.
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12. The method for drying waferlike substrates as claimed in claim 11, comprising removing liquid remnants between the waferlike substrates and the element of the device by way of the faces of the element of the device that border the support positions and fall away.
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13. The method for drying waferlike substrates as claimed in claim 12, wherein there is no active removal of the liquid remnants between the waferlike substrates and the element of the device.