

Method for producing semiconductor wafers composed of silicon

5 The invention relates to a method for producing semiconductor wafers composed of silicon, comprising pulling a single crystal at a seed crystal from a melt heated in a crucible, supplying heat to the center of the crucible bottom, and slicing the semiconductor wafers from the pulled single crystal.

10

The crucible usually consists of a material containing silicon dioxide, such as quartz. It is generally filled with chunks and/or with granules composed of polycrystalline silicon, the latter being melted with the aid of a side heater arranged around the crucible. After a phase of thermal stabilization of the melt, a monocrystalline seed crystal is dipped into the melt and raised. In this case, silicon crystallizes at that end of the seed crystal which has been wetted by the melt. The crystallization rate is substantially influenced by the speed at which the seed crystal is raised (crystal lifting speed), and by the temperature at the interface where molten silicon crystallizes. Through suitable control of these parameters, firstly a section referred to as a thin neck is pulled, in order to eliminate dislocations, followed by a conical section of the single crystal and, finally, a cylindrical section of the single crystal, from which the semiconductor wafers are subsequently sliced.

30

Liberated gaseous inclusions in the crucible material, gas that surrounds the chunks and/or the granules, silicon oxide that arises in the melt and gas that diffuses into the melt are regarded as possible causes of the arising of voids referred to as pinhole defects in the single crystal. They arise if small gas bubbles pass to the interface between the growing single crystal and the melt and if the single crystal

35

crystallizes around them. If the separating planes intersect the pinhole defects during the process of slicing the semiconductor wafers, the resulting semiconductor wafers have circular depressions or holes
5 having a diameter which can typically be from a few micrometers up to a few millimeters. Semiconductor wafers in which such pinhole defects are present are unusable as substrate wafers for producing electronic components.

10

Therefore, a series of proposals as to how the formation of such pinhole defects can be suppressed have already been published. Many of these proposals direct the focus onto improving the properties of the
15 crucible material. However, the crucibles improved in this respect generally are more expensive or entail other disadvantages, for example because they liberate substances which are responsible for the formation of dislocations in the single crystal.

20

Other proposals concentrate on suppressing or eliminating small bubbles during the period of the melting of the chunks and/or granules. Thus, by way of example, US 2008/0011222 A1 recommends concentrating
25 the heating power of the side heater firstly onto the side surface of the crucible and subsequently onto the base surface of the crucible. What is disadvantageous about such measures is that they no longer influence the arising of small bubbles and the movement thereof
30 to the interface as soon as the growth of the single crystal has begun.

It is an object of the present invention to propose a method which comprises at least one measure which
35 counteracts the formation of pinhole defects in the single crystal and which is effective during the process of pulling the single crystal.

The object is achieved by means of a method for producing semiconductor wafers composed of silicon, comprising

5 pulling a single crystal at a seed crystal from a melt heated in a crucible;
supplying heat to the center of the crucible bottom with a heating power which, in the course of a cylindrical section of the single crystal being pulled, is increased at least once to not less than 2 kW and is
10 then decreased again; and
slicing the semiconductor wafers from the pulled single crystal.

The inventors have ascertained that the frequency of
15 pinhole defects in semiconductor wafers composed of silicon decreases significantly if the temperature field in the region of the crucible bottom, during the process of pulling the cylindrical section of the single crystal, is changed at least once in such a way
20 that the highest temperature in the crucible bottom migrates from a position at the edge of the crucible bottom as far as the center of the crucible bottom. It is supposed that, in the course of this, small gas bubbles that adhere to the inner wall of the crucible
25 bottom are detached by a convectively driven melt flow that transports them as far as the free surface of the melt, said free surface not being covered by the crucible and the growing single crystal. In this way, the small gas bubbles can leave the melt without
30 passing to the interface between the growing single crystal and the melt.

The change in the temperature field is preferably effected with the aid of a heating device (crucible
35 bottom heater) that is adjacent to the crucible bottom and can be lifted and lowered with the crucible. For this purpose, the heating power of the crucible bottom heater is increased at least once to not less than

2 kW, preferably to 2-5 kW, and then decreased again. The heating power is preferably increased at least once from 0 kW to 2-5 kW and then decreased to 0 kW again. An increase in the heating power to less than 2 kW has
5 only a small influence on avoiding pinhole defects, and an increase to more than 5 kW subjects the crucible to thermal stress to an inappropriate extent and can be a trigger for the formation of dislocations in the single
crystal.

10

The heating power of the crucible bottom heater is preferably increased in a manner following a ramp within a time period which is not shorter than 90 min and is not longer than 900 min. In this case, the rate
15 at which the single crystal is pulled from the melt is preferably 0.3 to 0.8 mm/min, particularly preferably 0.45-0.65 mm/min. The ramp comprises a section with preferably linearly rising heating power of the crucible bottom heater, if appropriate a section with
20 constant heating power of the crucible bottom heater, and a section with falling heating power of the crucible bottom heater. The section with constant heating power preferably extends over a time period of 0-90 min. A heating power profile comprising 1-10 of
25 such ramps is particularly preferred.

Furthermore, it is preferred for the transport of small gas bubbles to the free surface of the melt to be supported by a series of further measures. The
30 preferred measures include exposing the melt to the influence of a horizontal magnetic field or of a CUSP magnetic field with a magnetic flux density of not less than 50 mT at the edge of the crucible bottom. The edge of the crucible bottom is the location at the
35 transition from the cylindrical side wall of the crucible to the crucible bottom. It is particularly preferred to expose the melt to the influence of a CUSP magnetic field whose neutral surface intersects the

central longitudinal axis of the single crystal at a distance from the plane of the free surface of the melt of not less than 90 mm.

5 The preferred measures also include rotating the crucible at a speed of not more than 3 revolutions per minute, preferably at 1-2 revolutions per minute, and rotating the single crystal at a speed of not less than 6 revolutions per minute, preferably at 6-12
10 revolutions per minute. The crucible and the single crystal are rotated in the same direction or in opposite directions. Rotation in opposite directions is preferred. The rotational speeds are accordingly specified as absolute values.

15 Finally, the preferred measures also include conducting inert gas, for example argon, to the free surface of the melt in order that gas escaping from the melt is removed from the region of the melt and of the single
20 crystal. The volumetric flow rate of the inert gas is preferably 600-12000 l/h, particularly preferably 1500-3000 l/h, at a pressure of preferably 11 to 80 mbar (1100-8000 Pa).

25 The invention is explained in greater detail below with reference to figures.

Figure 1 shows an arrangement that is particularly suitable for carrying out the method.

30 Figure 2 shows the configuration of a crucible bottom heater that is particularly suitable for carrying out the method.

35 Figure 3 shows the temporal profile of the heating power of the crucible bottom heater in accordance with one preferred embodiment.

Figure 4 shows the spatial movement of the highest temperature on the inner wall of the crucible in a manner dependent on the temporal alteration of the heating power of the crucible bottom heater.

5

The arrangement in accordance with figure 1 comprises a crucible 4, which is mounted into a supporting crucible 5 and which contains a melt composed of silicon. The crucible preferably consists of quartz and has a diameter that preferably corresponds to 2 to 4 times the diameter of the single crystal 8. The crucible 4 and the supporting crucible 5 rest on a crucible shaft that can be lifted and lowered and are surrounded by a side heater 6 embodied as a resistance heater. By means of the side heater, heat is transferred to the melt substantially from the side. A magnetic device is situated on the outside adjoining the side heater 6, by means of which magnetic device the melt is exposed to the influence of a horizontal magnetic field or of a CUSP magnetic field. The illustration shows coils suitable for impressing a CUSP magnetic field on the melt.

A further stationary bottom heater 7 embodied as a resistance heater is arranged below the supporting crucible around the crucible shaft. By means of the stationary bottom heater, heat is transferred to the melt substantially from below.

The single crystal 8 is pulled at a seed crystal from the melt, shielded against thermal radiation from the outside by a heat shield 2 and cooled by a cooler 1, through which coolant flows. The nominal diameter of the single crystal composed of silicon is preferably 300 mm or 450 mm. The distance between the free surface of the melt and the lower boundary 3 of the heat shield 2 is preferably 20-30 mm. The distance between the free

surface of the melt and the lower boundary of the cooler 1 is preferably 160-200 mm.

5 A crucible bottom heater 13 embodied as a resistance heater is integrated in the head of the crucible shaft, the heating power of said crucible bottom heater being altered according to the invention in order that small gas bubbles 11 that adhere to the inner wall of the crucible 4 are detached by correspondingly directed melt flows 10 and 12 and are transported to the free surface of the melt. From there, the small gas bubbles together with silicon oxide escaping from the melt are taken up by an inert gas flow 9 directed to the free surface of the melt and are removed from the region of the melt and of the growing single crystal.

20 Details of the configuration of a crucible bottom heater that is particularly suitable for carrying out the method are illustrated in figure 2. Said crucible bottom heater comprises a heating spiral 14 composed of graphite, which is supplied with electric AC current via inner and outer current feeds 15 and 16 led through the crucible shaft. The heating spiral is thermally insulated at the bottom by a plate 17 and laterally by a ring 18 composed of carbon fiber reinforced carbon (CFC). The inner wall of the ring is lined with a metallic reflector 19. In addition to the features illustrated, the heating spiral can be embodied in meandering fashion or be magnetically shielded in order to protect it against interactions with the magnetic field impressed on the melt.

35 Figure 3 shows how the heating power of the crucible bottom heater heater 13 is changed in the course of time in accordance with one preferred embodiment of the invention. Said heating power is changed in a manner following a ramp comprising a linear section and a constant section. The time axis is specified in the

unit of length L of grown single crystal. Given a typical crystal lifting speed for single crystals having a nominal diameter of 300 mm of 0.55 mm/min, the length $L = 5$ cm corresponds to a time period of approximately 90 min. The section with linearly rising heating power of the crucible bottom heater extends over a time period that is somewhat shorter than the time required to pull a length of 100 mm of the single crystal. The section with constant heating power of the crucible bottom heater extends over a time period that is somewhat longer than the time required to pull a length of 50 mm of the single crystal.

The change in the heating power of the crucible bottom heater in a manner that follows the ramp has the effect illustrated in figure 4 that the highest temperature (T_{max}) in the crucible bottom migrates from a position P_1 at the edge of the crucible bottom via an intervening position P_2 as far as the center P_3 of the crucible bottom. In the course of this, small gas bubbles that adhere to the inner wall of the crucible bottom are detached by a convectively driven melt flow and transported to the free surface of the melt, said free surface not being covered by the crucible and the growing single crystal.

Example:

A series of single crystals composed of silicon having a nominal diameter of 300 mm were pulled from a crucible having a diameter of 28 inches (711.2 mm) by means of the arrangement shown in figure 1, in accordance with the method according to the invention. The average crystal lifting speed was 0.55 mm/min during the process of pulling the cylindrical section of a single crystal. At the beginning of the process of pulling the cylindrical section of a single crystal, the heating power of the crucible bottom heater was

altered once in accordance with the ramp illustrated in figure 3. For comparison purposes, further single crystals were pulled under the same conditions, but without this alteration of the heating power of the crucible bottom heater. A statistical evaluation of the frequency of the occurrence of pinhole defects revealed a failure frequency approximately 30 times higher, on average, on account of such defects in the case of the semiconductor wafers that had been sliced from the single crystals pulled for comparison purposes.

Patent claims

1. A method for producing semiconductor wafers composed of silicon, comprising
 - 5 pulling a single crystal at a seed crystal from a melt heated in a crucible;
 - supplying heat to the center of the crucible bottom with a heating power which, in the course of a cylindrical section of the single crystal being pulled,
 - 10 is increased at least once to not less than 2 kW and is then decreased again; and
 - slicing the semiconductor wafers from the pulled single crystal.
- 15 2. The method as claimed in claim 1, wherein the heating power is increased in a manner following a ramp within a time period which is not shorter than 90 min and is not longer than 900 min.
- 20 3. The method as claimed in claim 1 or claim 2, comprising exposing the melt to the influence of a horizontal magnetic field or of a CUSP magnetic field with a magnetic flux density of not less than 50 mT at the edge of the crucible bottom.
- 25 4. The method as claimed in any of claims 1 to 3, comprising exposing the melt to the influence of a CUSP magnetic field whose neutral surface intersects the central longitudinal axis of the single crystal at a distance from the plane of the free surface of the melt
- 30 of not less than 90 mm.
5. The method as claimed in any of claims 1 to 4, comprising; rotating the crucible at a speed of not
- 35 more than 2 revolutions per minute and rotating the single crystal at a speed of not less than 6 revolutions per minute.

6. The method as claimed in any of claims 1 to 5, comprising conducting inert gas to the free surface of the melt at a volumetric flow rate of 600-12000 l/h at a pressure of 1100-8000 Pa.