

**A method and an apparatus for growing a silicon single crystal
from a melt**

The present disclosure relates to a method and an apparatus for
5 growing a silicon single crystal from a melt. More specifi-
cally, it relates to a method for growing a silicon single
crystal according to the Czochralski method while imposing a
horizontal magnetic field on the melt, the so-called HMCZ
method.

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It is known, e.g. from EP 0 745 706 A1, that imposing a hori-
zontal magnetic field on the melt reduces melt convection and
the dissolution of SiO from the crucible. As a consequence,
imposing a horizontal magnetic field on the melt is a suitable
15 strategy for producing silicon single crystals having a rela-
tively low oxygen concentration.

It is further known that the oxygen concentration in a silicon
single crystal can be lowered by increasing the flow rate of
20 inert gas flowing between the silicon single crystal and a heat
shield to a melt free surface. The increased gas flow rate
enhances the transport of SiO evaporating from the melt so that
less oxygen is incorporated in the growing silicon single
crystal.

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JP2004-196569 A discloses a HMCZ method comprising simultane-
ously controlling the axial position of the horizontal magnetic
field and the intensity of the gas flow in order to produce
low-oxygen silicon single crystals. However, controlling the
30 axial position of the horizontal magnetic field requires a
complex control system.

Embodiments of the present invention seek to provide a method which is suitable to
produce low-oxygen silicon single crystals

and which requires minor efforts for controlling the oxygen concentration.

According to the first aspect of the invention, there is provided a method for growing a silicon single crystal from a melt, comprising
providing the melt in a crucible;
imposing a horizontal magnetic field on the melt having a magnetic induction B at a field center C ;
directing a gas between the silicon single crystal and a heat shield to a melt free surface, and
controlling the gas such that the gas is forced to flow in a non-axisymmetric way with respect to a center axis M of the crucible over a region of the melt free surface which extends in a direction substantially perpendicular to the magnetic induction B .

According to the second aspect of the invention, there is provided an apparatus for growing a silicon single crystal from a melt, comprising
a crucible for holding the melt;
a magnetic system imposing a horizontal magnetic field on the melt, the magnetic field having a magnetic induction B at a field center C ;
a heat shield surrounding the silicon single crystal, the heat shield having a lower end which is connected to a bottom cover facing a melt free surface and having a non-axisymmetric shape with respect to a center axis M of the crucible, such that a gas which is directed between the silicon single crystal and the heat shield to the melt free surface is forced by the bottom cover to flow over a region of the melt free surface which extends in a direction substantially perpendicular to the magnetic induction B , wherein the bottom cover comprises a ring section which is surrounded by a brim section and a collar section, the brim section and the collar section forming a channel which has an opening for directing the gas over the region of the melt free surface.

By using embodiments of the present invention, it is possible to grow silicon single crystals with an oxygen concentration of less than 5×10^7 atoms/cm³ (according to new ASTM) in at least more than 50% of the length of the cylindrical part of the silicon single

crystal, preferably at least more than 70 % and most preferably more than at least 80 %.

The horizontal magnetic field which is imposed on the melt
5 suppresses thermal convection in the melt mainly in a part of
the melt which extends parallel to the magnetic induction B.
According to embodiments of the present invention, a gas which is directed to
the melt free surface is forced to flow over a region of the
melt free surface where the evaporation of SiO from the melt is
10 enhanced due to thermal convection which is not suppressed by
the horizontal magnetic field. Controlling of the gas to flow
over this region of the melt free surface increases the removal
of SiO and significantly reduces the oxygen concentration in
the melt and the silicon single crystal.

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According to another embodiment, the invention also provides a
solution for reducing the consumption of inert gas which is
needed for controlling the oxygen concentration in silicon
single crystals having large diameters like 300 mm, 450 mm or
20 more. Conventionally, the flow rate of inert gas which is
needed to achieve a target concentration of oxygen in the grown
silicon single crystal depends on the diameter of the single
crystal. For example, a higher flow rate of argon is needed to
maintain a certain oxygen concentration in a silicon single
25 crystal having a diameter of 300 mm compared to the flow rate
which is necessary to maintain the same oxygen concentration in
a single crystal having a diameter of 200 mm. For technical
reasons like insufficient pump and vacuum systems it becomes
more and more difficult to provide the required gas flow, if
30 silicon single crystals having diameters of more than 300 mm
have to be pulled in a conventional manner. However, by per-
forming the method according to embodiments of the present invention such diffi-
culties can be avoided since a lower flow of inert gas is
needed for achieving a certain oxygen target concentration in
35 the single crystal compared to the flow rate needed for achie-

ving the same oxygen target concentration by performing a conventional method.

The horizontal magnetic field is commonly generated by means of
5 a magnetic system comprising several coils which are arranged symmetrically (with respect to a crucible axis M) around the crucible. The field center C defined in accordance with embodiments of the claimed invention is the intersection of a horizontal plane dividing the coils into halves and axis M of the crucible. The
10 magnetic induction B represents the magnetic induction of the horizontal magnetic field at the field center C.

Fig.1 is a diagrammatic cross-sectional view showing typical features of a furnace suitable for growing silicon single cry-
15 stals according to the HMCZ method and features of the claimed invention.

A crucible 1 holding a melt 2 is arranged within a housing 3 and rests on a lifting shaft 4. A single crystal 5 is pulled
20 from the melt by a pulling mechanism 16 while a horizontal magnetic field is imposed on the melt. A heat shield 6 surrounding the single crystal is provided to protect the crystal from heat radiation radiated from a side heater 7 which is disposed around the crucible 1. According to a preferable
25 embodiment a further heater 18 is disposed under the crucible. The housing is steadily purged with a gas entering the housing by a gas inlet and exiting the housing by a number of gas exhaust openings 17. The gas is directed between the single crystal and the heat shield to a melt free surface 8 and
30 further driven from the melt free surface between the heat shield and the crucible wall to the gas exhaust openings 17. The gas is preferably directed between the silicon single crystal and the heat shield to the melt free surface in a non-axisymmetric way with respect to the center axis M. The
35 magnetic field is generated by coils 9 which are symmetrically

arranged around the crucible. The field center C of the horizontal magnetic field is represented by the intersection of a horizontal plane dividing the coils into halves and a center axis M of the crucible. The magnetic induction at the field center is represented by the magnetic induction B. In accordance with the present invention the heat shield 6 comprises a bottom cover 10 which is connected, e.g. fixed by screws, to the lower end of the heat shield and faces the melt free surface 8. The bottom cover is non-axisymmetric with respect to the center axis M of the crucible and serves as a tool for controlling the gas to flow over a region of the melt free surface which extends in a direction substantially perpendicular to the magnetic induction B, i.e. as a tool for controlling the gas to flow over the melt free surface in a non-axisymmetric way with respect to the center axis M. According to a preferred embodiment of the invention, the heat shield is attached to a support in a manner which enables turning of the heat shield. Turning the heat shield and the bottom cover which is connected thereto allows to more precisely control the gas flowing over the region of the melt free surface. Turning the heat shield to the left (right) will direct the gas flow to the left (right) of the region. It is also preferred that the exhaust openings 17 are disposed in a non-axisymmetric manner with respect to the crucible axis M in order to promote the gas flowing over the region of the melt free surface which extends in a direction substantially perpendicular to the magnetic induction B.

Fig.2 depicts the bottom cover according to a preferred embodiment. The bottom cover comprises a ring section 11, a brim section 12 and a collar section 13. The brim section can be flat or convexly or concavely bent. The ring has an inner diameter which is sufficiently large so that the silicon single crystal can be pulled through. The brim section extends horizontally from the ring and the collar section is connected

to the outer edge of the brim section and extends vertically towards the melt.

The effect of the invention is further explained by referring to Figs.3 and 4, wherein Fig.3 is a cross-sectional view of Fig.4 and represents an axial cut through the single crystal in a direction parallel to the direction of the magnetic induction B. Mainly the single crystal 5, the crucible 1, the melt 2 and the bottom cover 10 are shown. Arrows "Si" depict the direction of the melt convection. Arrows "Ar" depict the direction of the flow of a gas, e.g. an inert gas like argon, which is initially directed between the heat shield (not shown) and the single crystal to the melt free surface 8.

The bottom cover 10 is non-axisymmetrically shaped such that the gas which is directed between the single crystal and the heat shield to the melt free surface is forced to flow over a region of the melt free surface which extends in a direction substantially perpendicular to the magnetic induction B. In this region, the evaporation rate of SiO is enhanced since thermal convection "Si" in the melt is less influenced by the horizontal magnetic field and the gas flow "Ar" readily removes SiO evaporating from the melt in this region.

The region preferably extends over a sector of the melt free surface having a center angle α which is not less than 45° and not more than 135° , wherein the center axis D of the sector is aligned perpendicular to the magnetic induction B or, due to the influence of crucible rotation, is directed in a direction deviating up to -30° or $+30^\circ$ from the perpendicular alignment.

The brim section 12, the collar section 13, the melt free surface 8 and the silicon single crystal 5 form the boundaries of a channel 14 which controls the gas to flow along the inner wall of the collar section towards an opening 15 in the collar

section. The bottom cover is disposed such that the gas exiting the opening flows over the region of the melt free surface which extends in a direction substantially perpendicular to the magnetic induction B. The brim section 12 and the collar
5 section 13 are shaped preferably to extend transversely to the magnetic induction B. This enables the gas flowing between the melt surface and the brim section with enhanced velocity and further improves the removal rate of SiO from the melt.

10 Figs.5 to 8 show the shape of the brim section according to preferred embodiments. The brim section may have a shape which is rectangular (Fig.5) or elliptical (Fig.7) or may have the shape of a rectangle having rounded ends (Fig.6) or ends which are elliptically broadened (Fig.8). In case the brim section is
15 enlarged transversely to the magnetic induction B, the ratio L/W of the length L and the width W of the brim section preferably satisfies the formula: $1.1 < L/W < 3.0$. The length L and the width W intersect in the center of the ring 11.

20 The bottom cover is preferably designed in a way to keep the influence of the bottom cover on the axial temperature gradient at the growth interface of the silicon single crystal as low as possible and to reduce power consumption due to absorption of heat radiation emitted from the melt. For this reason, the
25 bottom cover is preferably shaped such as not to substantially extend in the direction of the magnetic induction B. A preferred material for constructing the bottom cover is graphite.

30 Figs.9 and 10 represent a view on the top of the silicon melt free surface without the crystal and the heat shield being shown. It is demonstrated that the center axis D of the sector is aligned perpendicular to the magnetic induction B or in a direction deviating by an angle β of up to $\pm 30^\circ$ from the
35 perpendicular alignment. The algebraic sign of the angle β

depends on the direction of rotation of the crucible, i.e. clockwise (Fig.10) or counter-clockwise (Fig.9) rotation.

Claims:

1. A method for growing a silicon single crystal from a melt, comprising
 providing the melt in a crucible;
 5 imposing a horizontal magnetic field on the melt having a magnetic induction B at a
 field center C;
 directing a gas between the silicon single crystal and a heat shield to a melt free
 surface, and
 controlling the gas such that the gas is forced to flow in a non-axisymmetric way with
 10 respect to a center axis M of the crucible over a region of the melt free surface which extends
 in a direction substantially perpendicular to the magnetic induction B.
2. A method according to claim 1, wherein the region forms a sector of the melt free
 surface having a center angle α which is not less than 45° and not more than 135° and
 15 wherein the sector comprises a center axis D which is aligned perpendicular to the magnetic
 induction B or in a direction deviating up to -30° or $+30^\circ$ from the perpendicular alignment.
3. A method according to claim 1 or claim 2, comprising controlling the gas to flow over
 the region of the melt free surface by turning the heat shield.
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4. A method according to claim 1 or claim 2, comprising driving the gas out of the
 crucible in a direction substantially perpendicular to the magnetic induction B.
5. An apparatus for growing a silicon single crystal from a melt, comprising
 25 a crucible for holding the melt;
 a magnetic system imposing a horizontal magnetic field on the melt, the magnetic
 field having a magnetic induction B at a field center C;
 a heat shield surrounding the silicon single crystal, the heat shield having a lower end
 which is connected to a bottom cover facing a melt free surface and having a non-
 30 axisymmetric shape with respect to a center axis M of the crucible, such that a gas which is
 directed between the silicon single crystal and the heat shield to the melt free surface is
 forced by the bottom cover to flow over a region of the melt free surface which extends in a
 direction substantially perpendicular to the magnetic induction B, wherein the bottom cover
 comprises a ring section which is surrounded by a brim section and a collar section, the brim
 35 section and the collar section forming a channel which has an opening for directing the gas
 over the region of the melt free surface.
6. An apparatus according to claim 5, wherein the region forms a sector of the melt free
 surface having a center angle α which is not less than 45° and not more than 135° and

wherein the sector comprises a center axis D which is aligned perpendicular to the magnetic induction B or in a direction deviating up to -30° or $+30^\circ$ from the perpendicular alignment.

5 7. An apparatus according to claim 5, wherein the brim section transversely extends to the magnetic induction B and has a shape which is rectangular or elliptical or has the shape of a rectangle having rounded ends or ends which are elliptically broadened.

10 8. An apparatus according to claim 5 or claim 7, wherein the brim section has a length L and a width W which intersect in the center of the ring section, wherein a ratio L/W fulfills the formula: $1.1 < L/W < 3.0$

15 9. An apparatus according to claim 5 or claim 6, comprising gas exhaust openings which are disposed in a non-axisymmetric manner with respect to the center axis M of the crucible to promote the gas to flow over the region of the melt free surface which extends substantially perpendicular to the magnetic induction B.