

Method And Device For Producing A Single Crystal Of Silicon, Which Single Crystal Is Doped With n-type Dopant

5 A subject of the invention is a method for producing a single silicon crystal doped with n-type dopant and having in a cylindrical portion an electrical resistivity of not more than 2 mohmcm, by pulling of the single crystal by the CZ method from a melt contained in a crucible. A further subject of the invention is an apparatus for implementing the method.

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Prior art/problems

The production of a single silicon crystal containing n-type dopant at a comparatively high concentration is especially challenging. The dopant is volatile and can form deposits which may trigger dislocations. It has proven advantageous to supply dopant
15 to the melt for the first time or additionally during a phase of the pulling of a cylindrical portion of the growing single crystal.

US 2010/0294999 A1 describes a method of this kind which envisages the blowing of a gas stream comprising the elemental dopant through a tube to the surface of the
20 melt. For this to occur, the solid dopant is sublimed in the pulling chamber and after admixture with a carrier gas is blown to the surface of the melt. A comparable procedure is adopted in a method which is explained in JP 2013-129 551 A.

CN 1 600 905 A and DE 11 2017 004 790 T5 advise providing multiple openings
25 through which gaseous dopant is blown to the surface of the melt.

Disadvantages of these proposals are that they require modifications to the zone immediately surrounding the growing single crystal (hot zone), to make space there for the dopant to sublime, and that distribution of the dopant lacks uniformity in spite of
30 the provision of multiple openings for blown introduction of the dopant.

It is an object of the invention to minimize modifications to the hot zone and to ensure a more uniform distribution of the dopant in the melt. The aim more particularly is to

avoid local spikes in the dopant concentration which if present raise the risk of triggering dislocations in the growing single crystal.

The object is achieved by means of a method for producing a single silicon crystal
 5 doped with n-type dopant and having in a cylindrical portion an electrical resistivity of not more than 2 mohmcm, by pulling of the single crystal by the CZ method from a melt contained in a crucible, comprising
 in the course of the pulling of the cylindrical portion of the single crystal, the supplying of a gas stream comprising gaseous dopant to a surface of the melt, wherein the gas
 10 stream is guided in a tubing system into a pulling chamber and through a heat shield which surrounds the growing single crystal, or along an outer surface of the heat shield, to an annular channel on a lower end of the heat shield and from there through nozzles to the surface of the melt.

15 The cylindrical portion of the single crystal has partly or preferably completely the electrical resistivity of not more than 2 mohmcm. Where the dopant is phosphorus, the electrical resistivity in the cylindrical portion of the single crystal is preferably not more than 1.2 mohmcm, more preferably not more than 1 mohmcm.

20 Particular modifications to the hot zone are avoided in particular by disposing the site at which solid dopant is sublimed into the gaseous state outside the pulling chamber. Furthermore, the path of the gaseous dopant leads in a tubing system through a heat shield or along an outer surface of the heat shield up to an annular channel of the lower end of the heat shield and from there through nozzles to the surface of the melt.

25 The outer surface of the heat shield denotes the side area of the heat shield which is first struck by the thermal radiation of a heating facility arranged around the crucible (crucible heater).

30 The dopant is sublimed outside the pulling chamber and is flush together with a carrier gas through the tubing system into the annular channel, from where it is guided through the nozzles to the surface of the melt.

At least two and preferably 4 to 100 nozzles are provided. The tips of the nozzles, where the gas stream composed of carrier gas and dopant gas emerges, have a distance of preferably not more than 20 mm from the surface of the melt.

- 5 With the aid of the arrangement of the nozzles, the gas stream is guided in a predetermined way onto the surface of the melt.

The nozzles may be arranged in such a way that the gas stream is guided in a direction perpendicular to the surface of the melt or toward the surface of the melt with
 10 a directional component toward an axis through the middle of the growing single crystal, or toward the surface of the melt with a directional component away from the axis through the middle of the growing single crystal.

The nozzles are preferably arranged in such a way that the gas stream of adjacent
 15 nozzles is guided in respective different directions – for example, alternately in two or three of the three above-designated directions, i.e. for example, alternately in a direction perpendicular to the surface of the melt and in a direction toward the axis through the middle of the growing single crystal, or alternately in a direction toward the axis through the middle of the growing single crystal and in a direction away from the
 20 axis through the middle of the growing single crystal.

It is particularly preferable to configure the nozzles swivelably and to orient their exit openings before the installation of the heat shield in such a way that during the pulling of the cylindrical portion the nozzles occupy a desired arrangement.

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The guiding of the gas stream to the surface of the melt during the pulling of the cylindrical portion of the single crystal may take place permanently or intermittently. Should the melt contain comparatively little or no dopant at the start of the pulling of the cylindrical portion of the single crystal, the gas stream is guided to the surface of
 30 the melt at this moment. The volume rate of the gas flow may be kept constant or changing. For example, the volume rate of the gas flow may be reduced with increasing crystallization of the single crystal, in order to compensate the accumulation of dopant in the melt through segregation.

The dopant consists preferably of one or more of the elements phosphorus, arsenic, and antimony, which are admixed in a facility for subliming dopant (sublimation facility) into the gaseous state. It is also possible, however, to use dopant of one or more chemical compounds of these elements that are already in gas form, examples
5 being compounds of these elements with hydrogen. In that case the sublimation facility is used only in order to mix dopant gas and carrier gas.

Also a subject of the invention is an apparatus for producing a single silicon crystal doped with an n-type dopant and having in a cylindrical portion an electrical resistivity
10 of not more than 2 mohmcm, comprising
a pulling chamber for pulling the single crystal by the CZ method;
a crucible for accommodating a melt of silicon;
a heat shield for shielding a growing single crystal;
a sublimation facility for converting solid dopant into gaseous dopant, and a tubing
15 system for supplying a gas stream comprising the gaseous dopant to a surface of the melt,
wherein the sublimation facility is arranged outside the pulling chamber, and the tubing system, leading through the heat shield or along an outer surface of the heat shield, opens out in an annular channel at the lower end of the heat shield, and the
20 annular channel has nozzles for guiding the gas stream to the surface of the melt.

The annular channel and nozzles consist preferably of a particularly corrosion-resistant material such as, for example, molybdenum, as does also at least that part of the tubing system whose distance from the surface of the melt is not more than
25 200 mm.

Arranged outside the pulling chamber is a sublimation facility which comprises a container for dopant and a container heater surrounding it. The container heater may possess a plurality of separately controllable heating zones, so improving control of
30 the amount of dopant subliming. Also present is a weighing cell, which detects the change in the weight of the container contents during the pulling of the single crystal. From this information it is possible to ascertain dopant consumption and control the further supply of dopant to the melt in a targeted way. Instead of or in addition to the weighing cell, it is possible to provide either a camera with image processing, used to

determine dopant consumption, or else, for the same purpose, a flow meter in that part of the tubing system which lies outside the pulling chamber.

On the entry side, the sublimation facility is connected to a flow regulator which is
5 used to mix carrier gas and dopant gas in the sublimation facility and guide the mixture into the pulling chamber. On the exit side, a part of the tubing system joins the sublimation facility to a flange on the outer wall of the pulling chamber. From there, the tubing system leads further up to an annular channel on the lower end of a heat shield which surrounds the growing single crystal. The heat shield is mounted in fixed
10 position relative to the surface of the melt.

Measures ought to be taken to prevent sublimed dopant precipitating as a solid within the tubing system. It is therefore preferred for that part of the tubing system which is arranged between the sublimation facility and the pulling chamber, including the
15 region of the flange of the outer wall of the pulling chamber, to be thermally insulated or provided regionally or completely with a tubing heater and heated from the outside by means of this heater.

The flow regulator, the weighing cell, and the container heater are preferably
20 connected to a regulating apparatus for the apparatus for pulling the single crystal. The regulating apparatus processes data from these components and regulates the heating power of the container heater and the delivery of carrier gas through the flow regulator, in order to ensure a supply of dopant to the melt that is predetermined or is computed within a control circuit.

25 According to a first embodiment of the invention, the tubing system leads further through the heat shield up to the annular channel. According to a second embodiment of the invention, the tubing system leads further along the outer surface of the heat shield up to the annular channel.

30 Distributed uniformly over the lower side of the annular channel are nozzles which point to the surface of the melt. The number of nozzles is preferably 4 to 100 nozzles. The nozzles are arranged in a predetermined way. In one possible arrangement, all of the nozzles are aligned perpendicularly to the surface of the melt, so that the gas
35 stream strikes the surface of the melt virtually at right angles. In another arrangement,

the nozzles have a tilted alignment radially toward the single crystal, in other words with a directional component or an axis through the middle of the growing single crystal. In a further arrangement, the nozzles have an alignment tilted radially away from the single crystal, in other words with a directional component away from the axis
 5 through the middle of the growing single crystal.

A particularly preferred arrangement is that in which the orientation of adjacent nozzles is different – for example, an arrangement in which the orientation of the nozzles alternates between the arrangement perpendicular to the surface, the tilted
 10 arrangement toward the single crystal, and the tilted arrangement away from the single crystal.

The invention is further elucidated below with reference to drawings.

15 **Brief description of the figures**

Fig. 1 shows an apparatus according to a first embodiment of the invention.

Fig. 2 shows an apparatus according to a second embodiment of the invention.

Fig. 3 shows possible arrangements of the nozzles directed from the annular channel
 20 to the surface of the melt.

List of Reference Numerals used

	1	growing single crystal
25	2	pulling chamber
	3	heat insulation
	4	gas inlet
	5	gas outlet
	6	crucible heater
30	7	annular channel
	8	outer crucible
	9	inner crucible
	10	heat shield
	11	tubing system

- 12** crucible shaft drive
- 13** crucible shaft
- 14** pulling shaft
- 15** pulling shaft drive
- 5 **16** seed crystal holder
- 17** seed crystal
- 18** facility for generating a magnetic field
- 19** regulating apparatus
- 20** surface of the melt
- 10 **21** facility for subliming dopant
- 22** nozzle
- 23** container for dopant
- 24** container heater
- 25** weighing cell
- 15 **26** flow regulator
- 27** carrier gas
- 28** axis through the middle of the growing single crystal
- 29** tubing heater

20 The apparatus according to Fig. 1 comprises a pulling chamber 2, which houses an inner crucible 9, which by means of a crucible shaft 13 can be rotated, raised, and lowered. The inner crucible 9 is supported by an outer crucible 8. The crucible shaft 13 is moved by a crucible shaft drive 12, which is connected to a regulating apparatus 19 of the apparatus for pulling the single crystal. Heat insulation 3 shields the inner

25 wall of the pulling chamber from thermal radiation delivered by a crucible heater 6 arranged around the crucibles 8 and 9. The pulling chamber 2 further comprises a gas inlet 4 and a gas outlet 5 for conducting a process gas such as argon or a process gas mixture such as argon and hydrogen during the pulling of a single crystal. A heat shield 10, which is mounted in fixed position, surrounds a growing single crystal 1

30 during the operation of the apparatus. The single crystal 1 grows on a seed crystal 17, which is clamped in a seed crystal holder 16, and is pulled upward by means of a pulling mechanism – for example, a pulling shaft 14 and a pulling shaft drive 15 – from the surface 20 of a melt of silicon, and is rotated about the axis 28 through its middle while it is being pulled. The pulling chamber 2 is surrounded by a facility 18 for

generating a magnetic field, such as a horizontal magnetic field or a CUSP magnetic field, for example.

Provision is made in accordance with the invention to arrange, outside the pulling
5 chamber 2, a facility 21 for supplying dopant (sublimation facility) and to connect it to
a tubing system 11 which guides dopant which has been converted into the gaseous
state in the sublimation facility 21, in the form of a gas stream comprising the gaseous
dopant and a carrier gas 27, into an annular channel 7 and from there, through
nozzles 22, to the surface 20 of the melt. The annular channel is arranged on the
10 lower end of the heat shield 10. The sublimation facility 21 comprises a container 23
for dopant, a container heater 24, and a weighing cell 25. The container heater 24, the
weighing cell, and a flow regulator 26, which supplies the carrier gas to the gaseous
dopant, are connected to the regulating apparatus 19. Around the tubing system 11, in
the region outside the pulling chamber 2, there is preferably a tubing heater 29
15 arranged, regionally or completely, for heating the tubing system 11.

According to the embodiment shown in Fig. 1, the tubing system 11 leads through the
heat shield 19 and opens out into the annular channel 7.

20 According to the embodiment shown in Fig. 2, the tubing system 11 leads along the
outer surface of the heat shield 19 into the annular channel 7.

The nozzles 22 are in a distributed arrangement over the side of the annular channel
7 that is opposite the surface of the melt, being distributed preferably with a uniform
25 distance, and are directed to the surface 20 of the melt, either only with a directional
component parallel to the axis 28 through the middle of the growing single crystal, or
with an additional directional component toward this axis, or with an additional
directional component away from this axis. Fig. 3 shows examples of such
arrangements of the nozzle. Particularly preferred is an arrangement of the nozzles
30 which implements alternately two or three of these three possibilities.

The above description of exemplary embodiments should be understood as an
illustrative description. The disclosure it makes enables the skilled person on the one
hand to understand the present invention and the advantages associated with it, and
35 on the other hand, within the understanding of the skilled person, also embraces

obvious alterations and modifications of the structures and methods described. It is therefore the intention that all such alterations and modifications, and also equivalents, should be covered by the scope of protection of the claims.

What is claimed is:-

1. A method for producing a single silicon crystal doped with n-type dopant and having in a cylindrical portion an electrical resistivity of not more than 2 mohmcm, by pulling
 5 of the single crystal by the CZ method from a melt contained in a crucible, comprising in the course of the pulling of the cylindrical portion of the single crystal, the supplying of a gas stream comprising gaseous dopant to a surface of the melt, wherein the gas stream is guided in a tubing system into a pulling chamber and through a heat shield which surrounds the growing single crystal, or along an outer surface of the heat
 10 shield, to an annular channel on a lower end of the heat shield and from there through nozzles to the surface of the melt.
2. The method as claimed in claim 1, wherein the dopant in the form of a chemical compound or in a molecular or atomic form of an element of the dopant is guided to
 15 the surface of the melt, and the dopant comprises one or more of the elements P, As and Sb.
3. The method as claimed in claim 1 or claim 2, wherein the dopant is passed through at least two nozzles to the surface of the melt.
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4. The method as claimed in any of claims 1 to 3, wherein the gas stream is guided by the nozzles in a direction perpendicular to the surface of the melt or toward the surface of the melt in a direction away from an axis through the middle of the single crystal or toward the surface of the melt in a direction toward the axis through the
 25 middle of the single crystal.
5. The method as claimed in any of claims 1 to 4, wherein the gas stream is guided to the surface of the melt by adjacent nozzles in respectively different directions.
- 30 6. The method as claimed in any of claims 1 to 5, wherein the tubing system is heated regionally or completely from the outside in the region outside the pulling chamber.
7. An apparatus for producing a single silicon crystal doped with an n-type dopant and having in a cylindrical portion an electrical resistivity of not more than 2 mohmcm,
 35 comprising

a pulling chamber for pulling the single crystal by the CZ method;
a crucible for accommodating a melt of silicon;
a heat shield for shielding a growing single crystal;
a sublimation facility for converting solid dopant into gaseous dopant, and a tubing
5 system for supplying a gas stream comprising the gaseous dopant to a surface of the
melt,
wherein the sublimation facility is arranged outside the pulling chamber, and the
tubing system, leading through the heat shield or along an outer surface of the heat
shield, opens out in an annular channel at the lower end of the heat shield, and the
10 annular channel has nozzles for guiding the gas stream to the surface of the melt.

8. The apparatus as claimed in claim 7, wherein there are at least two nozzles.

9. The apparatus as claimed in claim 7 or claim 8, wherein the nozzles are distributed
15 with uniform spacing over the annular channel.

10. The apparatus as claimed in any of claims 7 to 9, wherein the nozzles are aligned
such that the gas stream on emergence from the nozzles is guided in a direction
perpendicular to the surface of the melt or toward the surface of the melt in a direction
20 away from an axis through the middle of the single crystal or toward the surface of the
melt in a direction toward the axis through the middle of the single crystal.

11. The apparatus as claimed in claim 10, wherein the nozzles are aligned in such a
way that the gas stream on emergence from adjacent nozzles is guided in
25 respectively different directions to the surface of the melt.

12. The apparatus as claimed in any of claims 1 to 11, which comprises a tubing
heater which heats the tubing system regionally or completely from the outside in the
region outside the pulling chamber.