

REFLECTOR FOR SINGLE CRYSTAL FURNACE, SINGLE CRYSTAL FURNACE AND SINGLE CRYSTAL SILICON INGOT

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims a priority of the Chinese patent application No. 202310701935.1 filed on June 13, 2023, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure relates to the field of single crystal manufacturing technology, in particular to a reflector for a single crystal furnace, the single crystal furnace and a single crystal silicon ingot.

BACKGROUND

[0003] Most of the single crystal silicon ingots are fabricated using a Czochralski (CZ) method. In this method, based on the principle of condensation- crystallization-driven of a melt, a phase transition from a liquid to a solid is generated at an interface between the solid and the liquid due to a decrease in a temperature of the melt. In this method, a solid-state polycrystalline silicon raw material is placed in a quartz crucible and heated by a graphite heater to melt the polycrystalline silicon raw material therein, then the melt is subjected to processes including temperature profiling, dip, shoulder, over shoulder, body and tail processes, so as to finally pull a dislocation-free single crystal silicon ingot.

[0004] In addition, the single crystal silicon ingots include a P-type single crystal silicon ingot and an N-type single crystal silicon ingot depending on different dopants. Usually, the N-type single crystal silicon ingot is obtained through doping a group V element, and red phosphorus is mainly selected as the dopant for a heavily-doped N-type single crystal silicon ingot. It is widely recognized that, red phosphorus has such characteristics as being volatile, flammable and combustible and having a high

segregation coefficient. Hence, after the polycrystalline silicon raw material is melted, phosphorus is typically doped through gas-phase doping.

[0005] However, as a matter of experience, in a case of pulling the N-type single crystal silicon ingot, about 50% of the red phosphorus dopant volatilizes and leaves a liquid surface. In addition, silicon oxide generated by the reaction between a molten silicon and the quartz crucible also volatilizes. Hence, a large quantity of volatile matters is generated during the pulling of the N-type single crystal silicon ingot, and these volatile matters may be deposited onto a surface of an upper hot zone component in a case that they are not discharged from a single crystal furnace in time. Moreover, in a case that an inert gas is guided into a furnace body, the volatile matters deposited onto the surface of the upper hot zone component may fall into the silicon melt under the sweeping effect of the inert gas, and thereby a thermal shock occurs. In a case that the thermal shock reaches a solid-liquid interface, a wire breakage may occur, and a structure loss is caused for the single crystal silicon ingot, and thereby a crystal formation rate is adversely affected finally.

SUMMARY

[0006] Based on the above, the present disclosure intends to provide a reflector for a single crystal furnace, the single crystal furnace and a single crystal silicon ingot, so as to discharge volatile matters from the single crystal furnace effectively and in time during the pulling, thereby to ensure the crystal formation rate of the single crystal silicon ingot and improve the quality of the single crystal silicon ingot.

[0007] In addition, oxygen is uniformly guided to a solid-liquid interface effectively and in time, so as to ensure the uniformity of oxygen in the single crystal silicon ingot. Furthermore, it is able to ensure the uniformity of a temperature field at the solid-liquid interface in a radial direction, thereby to reduce the probability of twinning, and improve the yield of the single crystal silicon ingot.

[0008] The technical solution of the present disclosure is achieved as follows.

[0009] In a first aspect, the present disclosure provides in some embodiments a reflector for a single crystal furnace. The reflector includes a bottom surface that exhibits wave-like profile in a radial direction to guide an inert gas in such a manner that a flow rate of the inert gas increases.

[0010] Optionally, in some possible embodiments of the present disclosure, the bottom surface is configured in such a manner that a distance between a trough of the bottom surface and a liquid surface of a silicon melt is reduced by fitting an involute manner in the radial direction from a side close to a single crystal silicon ingot to a side away from the single crystal silicon ingot.

[0011] Optionally, in some possible embodiments of the present disclosure, the distance between the trough of the bottom surface and the liquid surface of the silicon melt has a maximum value of 65 mm to 75 mm, and a minimum value of 35 mm to 42 mm.

[0012] Optionally, in some possible embodiments of the present disclosure, the reflector is made of graphite.

[0013] Optionally, in some possible embodiments of the present disclosure, a pyrolytic boron nitride coating is deposited on a surface of the reflector.

[0014] In a second aspect, the present disclosure provides in some embodiments a single crystal furnace including the above-mentioned reflector.

[0015] Optionally, in some possible embodiments of the present disclosure, the single crystal furnace further includes a graphite crucible and a quartz crucible, the quartz crucible is arranged within the graphite crucible, and the reflector is arranged right above the quartz crucible.

[0016] In a third aspect, the present disclosure provides in some embodiments a single crystal silicon ingot pulled using the above-mentioned single crystal furnace.

[0017] The present disclosure provides the reflector for the single crystal furnace, the single crystal furnace and the single crystal silicon ingot. In the embodiments of the present disclosure, the bottom surface of the reflector that exhibits wave-like profile in the radial direction to guide an inert gas in such a manner that the flow rate of the inert

gas increases. As a result, it is able to discharge the volatile matters generated during the pulling in time, thereby enabling normal operation of the pulling procedure.

[0018] In addition, through the wave-like bottom surface, the distance between the reflector and the liquid surface changes continuously in the radial direction. On one hand, a melt gap and its spatial variation are very important during the pulling, and they directly affect convection of the melt, so an effective oxygen content in the single crystal silicon ingot is affected.

[0019] On the other hand, due to the spatial variation in the melt gap, the radial convection close to the liquid surface increases, so as to guide oxygen to the solid-liquid interface uniformly, effectively and timely, thereby ensuring the uniformity of oxygen in the single crystal silicon ingot. In addition, through increasing the convection of the melt in the radial direction, it is able to ensure the uniformity of the temperature field at the solid-liquid interface in the radial direction. As a result, it is able to reduce the probability of twinning, and improve the yield of the single crystal silicon ingot.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] Fig. 1 is a schematic view showing a conventional single crystal furnace for pulling a single crystal silicon ingot;

[0021] Fig. 2 is a schematic view showing a reflector for a single crystal furnace according to an embodiment of the present disclosure;

[0022] Fig. 3 is a schematic view showing a change in a distance between a bottom surface of the reflector and a liquid surface according to an embodiment of the present disclosure; and

[0023] Fig. 4 is a schematic view showing a single crystal furnace according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0024] The technical solution in the embodiments of the present disclosure will be described hereinafter in a clear and complete manner in conjunction with the drawings.

[0025] Before describing the technical solution of the present disclosure, it should be appreciated that, unless otherwise defined, any technical or scientific term used herein shall have the common meaning understood by a person of ordinary skills.

[0026] In addition, it should be appreciated that, such terms as “include” or “including” or any other variations in the specification and the appended claims intend to provide non-exclusive coverage, so that a procedure, method, system, product or device including a series of steps or units may also include any other steps or units not listed herein, or may include any inherent steps or units of the procedure, method, system, product or device.

[0027] Fig. 1 is a schematic view showing a conventional single crystal furnace 1 for fabricating a single crystal silicon ingot. As shown in Fig. 1, the single crystal furnace 1 includes: a furnace body 10 configured to define a chamber; a quartz crucible 20 arranged at the bottom of the chamber defined by the furnace body 10 and configured to receive a solid-state polycrystalline silicon raw material (or polycrystalline silicon melt) at an initial stage for fabricating the single crystal silicon ingot S; a graphite heater 30 surrounding the quartz crucible 20; an inverted-cone reflector 40; a gas inlet 50; and a gas outlet 60.

[0028] During the fabrication of the single crystal silicon ingot, after a predetermined amount of polycrystalline silicon raw material is placed into the quartz crucible 20, the polycrystalline silicon raw material is heated by the graphite heater 30, so as to melt the polycrystalline silicon raw material into a silicon melt MS.

[0029] On one hand, the reflector 40 is mainly used to prevent the occurrence of any thermal radiation caused by the graphite heater 30 on the single crystal silicon ingot S, and ensure a temperature gradient for the growth of the single crystal silicon ingot S, thereby to ensure a crystal formation rate of the single crystal silicon ingot S. On the other hand, the reflector 40 is configured to guide an inert protective gas, e.g., argon

gas, to be above the silicon melt in the quartz crucible 20 from top to bottom, so as to accelerate the gas at a liquid surface, thereby to discharge volatile impurities rapidly.

[0030] The gas inlet 50 is configured to allow an inert gas, e.g., argon gas, to pass therethrough during the pulling.

[0031] The gas outlet 60 is configured to, during the pulling, allow volatile matters to be discharged therethrough to the outside of the furnace body 10 under the effect of the inert gas.

[0032] It should be appreciated that, the single crystal furnace 1 further includes a seed cable 70. During the pulling of the single crystal silicon ingot S, after a predetermined amount of polycrystalline silicon raw material is placed into the quartz crucible 20, the quartz crucible 20 is heated to melt the polycrystalline silicon raw material into the silicon melt MS. After a temperature at a liquid surface of the silicon melt MS is stable, a seed crystal is lowered via the seed cable 70 to a solid-liquid interface of the silicon melt MS, and then the silicon melt is subjected to such processes as dip, necking, shoulder, body and tail processes, so as to finally obtain the single crystal silicon ingot S with a certain length.

[0033] It should be appreciated that, a lifting head 80 coupled to the seed cable 70 is further arranged at a top of the furnace body of the single crystal furnace 1. The lifting head 80 is mainly used to rotate and lift the seed ZJ, and record data about the seed ZJ, e.g., displacement of the seed ZJ.

[0034] It should be appreciated that, the single crystal furnace in Fig. 1 further includes any other structures not shown in Fig. 1, e.g., a crucible lifting device, which will not be particularly defined herein.

[0035] To be specific, in a case that the single crystal silicon ingot S is pulled using the single crystal furnace 1, at first the high-purity polycrystalline silicon raw material is placed into the quartz crucible 20, and the quartz crucible 20 is heated continuously by the graphite heater 30 while rotating the quartz crucible 20 by a crucible rotation mechanism (not shown), so as to enable the polycrystalline silicon raw

material in the quartz crucible 20 to be in a molten state, i.e., to be melted into the silicon melt MS.

[0036] A heating temperature is maintained at about 1000 °C, and usually a gas in the furnace is an inert gas, so that the polycrystalline silicon raw material is melted and meanwhile undesired chemical reaction does not occur.

[0037] It should be appreciated that, during the pulling, the inert gas enters the furnace body 10 via the gas inlet 50, moves downward along the reflector 40, sweeps over a surface of the single crystal silicon ingot S, flows through the solid-liquid interface of the silicon melt MS, sweeps over the liquid surface, moves upward along an inner wall of the quartz crucible 20 to bypass around the quartz crucible 20, moves downward along an outer wall of the graphite crucible (not shown), and then reaches the gas outlet 60.

[0038] During the entire pulling process, a large quantity of volatile matters is generated. For example, in a case of pulling the N-type single crystal silicon ingot, the volatile matters include not only silicon oxide generated due to the reaction of the silicon melt with the quartz crucible, but also a volatile matter of the dopant, i.e., red phosphorus. During the entire pulling process, these volatile matters may be deposited onto a surface of the reflector 40. Hence, through the flow of the inert gas, these volatile matters are blown and then discharged out of the furnace body 10. However, in some cases, due to an insufficient blowing force of the inert gas, these volatile matters may fall into the silicon melt, and thereby the quality of the single crystal silicon ingot may be adversely affected.

[0039] It should be appreciated that, under normal circumstances, a flow rate of the inert gas at the gas inlet is increased to increase the blowing force, so as to flow the volatile matters. However, in a case that the flow rate of the inert gas is too large, a seed lifting system and the single crystal silicon ingot may shake, resulting in a fluctuation in the solid-liquid interface. Due to the fluctuation in the solid-liquid interface, such a defect as twinning occurs in the single crystal silicon ingot, and the oxygen distribution

is non-uniform. In addition, the severe shaking also leads to a change in the structure of the single crystal silicon ingot.

[0040] Based on the above, in order to prevent the single crystal silicon ingot from shaking, effectively discharge the volatile matters in time, and perform the pulling normally, the present disclosure intends to provide a reflector with a wave-like bottom surface, so as to, based on the Laval effect, continuously accelerate the inert gas in a case that the inert gas flows through the solid-liquid interface and sweeps over the liquid surface of the silicon melt, thereby to discharge the volatile matters in time and perform the pulling normally.

[0041] In addition, through the reflector, it is able to prevent the flow rate of the inert gas from being increased at the gas inlet, thereby to prevent the single crystal silicon ingot S from shaking.

[0042] To be specific, Fig. 2 shows a reflector 2 for a single crystal furnace according to an embodiment of the present disclosure. The reflector 2 includes a bottom surface 21 that exhibits wave-like profile in a radial direction to guide an inert gas in such a manner that a flow rate of the inert gas increases.

[0043] It should be appreciated that, in the embodiments of the present disclosure, the bottom surface 21 of the reflector 2 that exhibits wave-like profile in the radial direction to guide an inert gas in such a manner that the flow rate of the inert gas increases. As a result, it is able to discharge volatile matters generated during the pulling in time, and perform the pulling normally.

[0044] In addition, through the wave-like bottom surface 21, a distance between the reflector 2 and a liquid surface YM changes continuously in the radial direction. On one hand, the melt gap and the spatial variation in the melt gap is very important during the pulling, and they directly affect convection of a melt, so an effective oxygen content in a single crystal silicon ingot S is affected.

[0045] On the other hand, due to the spatial variation in the melt gap, the radial convection close to the liquid surface increases, so as to uniformly guide oxygen to the solid-liquid interface YM effectively and in time, ensure the uniformity of oxygen in

the single crystal silicon ingot S. In addition, through increasing the convection of the melt in the radial direction, it is able to ensure the uniformity of the temperature field at the solid-liquid interface in the radial direction. As a result, it is able to reduce the probability of twinning, and improve the yield of the single crystal silicon ingot.

[0046] For the technical solution in Fig. 1, in some possible embodiments of the present disclosure, as shown in Fig. 3, the bottom surface 21 is configured in such a manner that a distance between a trough 31 of the bottom surface 21 and the liquid surface YM of a silicon melt is reduced by fitting an involute manner in the radial direction from a side close to a single crystal silicon ingot S to a side away from the single crystal silicon ingot S.

[0047] It should be appreciated that, in a case that the distance between the trough 31 of the bottom surface 21 and the liquid surface YM of the silicon melt is reduced by fitting an involute manner, it means that the distance between the trough 31 of the bottom surface 21 and the liquid surface YM is reduced gradually. To be specific, in a case that the inert gas enters a furnace 10 via the gas inlet 50, the inert gas moves downward along an inner wall of the reflector 2, sweeps over a surface of the single crystal silicon ingot S, flows through a solid-liquid interface of the silicon melt MS, and sweeps over the liquid surface YM. Based on the Laval effect, in a case that the inert gas flows through the trough 31, a melt gap between the liquid surface and the bottom surface decreases, so a pressure decreases, and thereby the flow rate of the inert gas increases.

[0048] In other words, in the radial direction away from the single crystal silicon ingot S, the distance between the trough 31 of the bottom surface 21 and the liquid surface YM decreases gradually, so as to accelerate the flow of the inert gas, thereby to discharge an oxide rapidly.

[0049] It should be appreciated that, in a case that the distance between the trough 31 of the bottom surface 21 and the liquid surface YM becomes smaller and smaller, the pressure between the bottom surface 21 and the liquid surface YM becomes smaller and smaller too, so the flow rate of the inert gas becomes larger and larger.

Along with a continuous increase in the flow rate of the inert gas, it is able to discharge the volatile matters in time during the pulling, and perform the pulling normally.

[0050] Based on the above, in some illustrative embodiments of the present disclosure, the distance between the trough 31 of the bottom surface 21 and the liquid surface YM of the silicon melt has a maximum value of 65 mm to 75 mm, and a minimum value of 35 mm to 42 mm.

[0051] In the radial direction away from the single crystal silicon ingot S, the distance between the trough 31 of the bottom surface 21 and the liquid surface YM is reduced by fitting an involute manner, and the distance has a maximum value of 65 mm to 75 mm and a minimum value of 35 mm to 42 mm. Optionally, during the implementation, in the radial direction away from the single crystal silicon ingot S, the distance between the trough 31 of the bottom surface 21 and the liquid surface YM has a maximum value of 75 mm and a minimum value of 42 mm.

[0052] It should be appreciated that, in the radial direction away from the single crystal silicon ingot S, the distance between the trough 31 of the bottom surface 21 and the liquid surface YM is set according to a target value of a melt gap. It should be appreciated that, a size of the melt gap directly determines an axial temperature difference at the solid-liquid interface, and the axial temperature difference needs to match with a lifting speed for the crystal growth. In a case that the distance between the trough 31 of the bottom surface 21 and the liquid surface YM is within a predetermined range, the axial temperature difference may match with the lifting speed for the crystal growth in a better manner, so as to achieve the stable growth of the crystal.

[0053] For example, in a case that the reflector 2 provided in the embodiments of the present disclosure has a structure as shown in Fig. 3, considering the matching between the axial temperature difference and the lifting speed for the crystal growth, in the radial direction away from the single crystal silicon ingot S, distances D between the troughs 31 and the liquid surface YM are 75 mm, 65 mm and 55 mm respectively. Based on this, in a case that the inert gas flows through a gap between the reflector 2

and the liquid surface YM, the flow rate of the inert gas increases gradually, so as to discharge the volatile matters in time and stably during the pulling.

[0054] In addition, in a case that the distance between the trough 31 of the bottom surface 21 and the liquid surface YM changes gradually, the flow rate of the inert gas increases stably and the convection of the melt changes stably during the pulling, so as to enable the temperature field to change uniformly during the pulling, thereby to control the uniformity of the oxygen content in the single crystal silicon ingot.

[0055] It should be appreciated that, such expressions as “illustratively” and “for example” are merely used to show examples, explanations or description. Any illustrative or exemplary embodiment or scheme in the embodiments of the present disclosure shall not be construed as being superior over the other embodiment or scheme. Definitely, these words intend to exhibit relevant concepts in a concrete manner.

[0056] For the technical solution in Fig. 1, in some possible embodiments of the present disclosure, the reflector 2 is made of graphite.

[0057] It should be appreciated that, the reflector 2 is made of graphite, so it is able to prevent the occurrence of any thermal radiation caused by the graphite heater 30 on the single crystal silicon ingot S, and ensure a temperature gradient for the growth of the single crystal silicon ingot S, thereby to ensure a crystal formation rate of the single crystal silicon ingot S.

[0058] Based on the above, in some illustrative embodiments of the present disclosure, a pyrolytic boron nitride coating is deposited on a surface of the reflector 2. The pyrolytic boron nitride coating is stable at a high temperature. In addition, the pyrolytic boron nitride coating has high chemical stability, and it does not react with the volatile matters during the pulling. Hence, the pyrolytic boron nitride coating is suitable for an environment including a large quantity of volatile matters, so as to improve a service life of the reflector.

[0059] Fig. 4 shows a single crystal furnace 4 provided in an embodiment of the present disclosure, and the single crystal furnace 4 includes the above-mentioned reflector 2.

[0060] For the single crystal furnace 4 in Fig. 4, in some possible embodiments of the present disclosure, the single crystal furnace 4 further includes a graphite crucible 90 and a quartz crucible 20, the quartz crucible 20 is arranged within the graphite crucible 90, and the reflector 2 is arranged right above the quartz crucible 20.

[0061] The present disclosure further provides in some embodiments a single crystal silicon ingot pulled using the above-mentioned single crystal furnace 4.

[0062] It should be appreciated that, the technical solutions in the embodiments of the present disclosure may be combined randomly in a case of no conflict.

[0063] The above are merely the preferred embodiments of the present disclosure, but shall not be construed as limiting the scope of the present disclosure. Any person skilled in the art may make modifications and substitutions without departing from the spirit of the present disclosure, and these modifications and substitutions shall also fall within the scope of the present disclosure. Hence, the scope of the present disclosure shall be subject to the scope defined by the appended claims.

What is claimed is:

1. A reflector for a single crystal furnace, wherein the reflector comprises a bottom surface that exhibits wave-like profile in a radial direction to guide an inert gas in such a manner that a flow rate of the inert gas increases.

2. The reflector according to claim 1, wherein the bottom surface is configured in such a manner that a distance between a trough of the bottom surface and a liquid surface of a silicon melt is reduced by fitting an involute manner in the radial direction from a side close to a single crystal silicon ingot to a side away from the single crystal silicon ingot.

3. The reflector according to claim 2, wherein the distance between the trough of the bottom surface and the liquid surface of the silicon melt has a maximum value of 65 mm to 75 mm, and a minimum value of 35 mm to 42 mm.

4. The reflector according to claim 1, wherein the reflector is made of graphite.

5. The reflector according to claim 2, wherein a pyrolytic boron nitride coating is deposited on a surface of the reflector.

6. A single crystal furnace, comprising the reflector according to any one of claims 1 to 5.

7. The single crystal furnace according to claim 6, further comprising a graphite crucible and a quartz crucible,

wherein the quartz crucible is arranged within the graphite crucible, and the reflector is arranged right above the quartz crucible.

8. A single crystal silicon ingot pulled using the single crystal furnace according to claim 6 or 7.