

SINGLE CRYSTAL FURNACE AND METHOD FOR FABRICATING SINGLE CRYSTAL SILICON

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims a priority of the Chinese patent application No. 202310473614.0 filed on April 27, 2023, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

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

BACKGROUND

[0003] Polycrystalline silicon is a major raw material for fabricating a solar photovoltaic product and a semiconductor product. Czochralski (Cz) method is a most commonly-used method for fabricating single crystal silicon. A high-purity solid-state polycrystalline silicon raw material is melted in a crucible of a crystal growth furnace (i.e., single crystal furnace) to obtain a melt, a seed moves downward through a seed pulling mechanism to be in contact with the melt in a molten state in the rotary crucible, and the seed is pulled using a certain process, and then the melt is solidified around the seed to form the single crystal silicon rod.

[0004] A defect property of the single crystal silicon rod depends sensitively on a growth condition and a cooling condition of a crystal. The single crystal furnace includes a water-cooling jacket to provide a stable longitudinal temperature gradient of a thermal field. However, in the related art, at a melting stage, the crucible is located at a low level, and a temperature of the water-cooling jacket is low, so the longitudinal temperature gradient of the thermal field is relatively large, and volatile matters easily gather on the water-cooling jacket. Later in a single crystal constant-diameter stage, the crucible is located at a high level, and the crystal is close to the water-cooling jacket,

so the temperature of the water-cooling jacket increases, and the longitudinal temperature gradient of the thermal field is relatively small. In other words, the temperature of the water-cooling jacket is not constant due to a change in a position of the single crystal silicon rod, so the longitudinal temperature gradient of the thermal field is not stable. In this regard, it is impossible to ensure the stable growth of the single crystal silicon rod, and thereby the fabricated single crystal silicon has many defects.

SUMMARY

[0005] In order to solve the above-mentioned technical problem, an object of the present disclosure is to provide a single crystal furnace and a method for fabricating single crystal silicon, so as to reduce the defects of the fabricated single crystal silicon.

[0006] In order to achieve the above-mentioned object, the present disclosure has the following technical solutions.

[0007] The present disclosure provides in some embodiments a single crystal furnace, including a furnace body. A crucible support assembly is arranged inside the furnace body, a crucible is arranged on the crucible support assembly, a guiding cylinder is arranged right above the crucible, a heater is arranged between an inner wall of the furnace body and a periphery of the crucible, and a seed pulling mechanism is arranged at a top of the furnace body. The single crystal furnace further includes: a water-cooling structure arranged at a side of the guiding cylinder away from the crucible support assembly, the water-cooling structure including a plurality of water-cooling regions independent of each other, and the plurality of water-cooling regions being arranged sequentially in a direction away from the guiding cylinder; and a mass flow controller configured to control flow rates and temperatures of cooling water in different water-cooling regions.

[0008] In some embodiments of the present disclosure, the mass flow controller is specifically configured to control the temperatures of the cooling water in the plurality of water-cooling regions to gradually decrease and/or control the flow rates of the cooling water in the plurality of water-cooling regions to gradually increase in a

direction away from the guiding cylinder before the growth of a single crystal silicon rod.

[0009] In some embodiments of the present disclosure, a difference between the temperatures in adjacent water-cooling regions is 1.5°C to 2.5°C.

[0010] In some embodiments of the present disclosure, the mass flow controller is specifically configured to control the temperatures of the cooling water in the plurality of water-cooling regions to gradually decrease and/or control the flow rates of the cooling water in the plurality of water-cooling regions to gradually increase along with the movement of the crucible in a direction close to the guiding cylinder during the growth of the single crystal silicon rod.

[0011] In some embodiments of the present disclosure, the mass flow controller is further configured to obtain a defect evaluation result of a single crystal silicon rod after the growth of the single crystal silicon rod, and adjust the flow rates and/or the temperatures of the cooling water in the water-cooling regions based on the defect evaluation result of the single crystal silicon rod.

[0012] In some embodiments of the present disclosure, the mass flow controller is specifically configured to reduce the temperatures of the cooling water in the water-cooling regions and/or increase the flow rates of the cooling water in the water-cooling regions in a case that the single crystal silicon rod has a V-rich defect, and increase the temperatures of the cooling water in the water-cooling regions and/or reduce the flow rates of the cooling water in the water-cooling regions in a case that the single crystal silicon rod has an N-rich defect.

[0013] In some embodiments of the present disclosure, the water-cooling structure includes three water-cooling regions.

[0014] The present disclosure further provides a method for fabricating single crystal silicon, applied to the above-mentioned single crystal furnace, including: controlling, by the mass flow controller, the temperatures of the cooling water in the plurality of water-cooling regions to gradually decrease and/or controlling the flow rates of the cooling water in the plurality of water-cooling regions to gradually increase

in a direction away from the guiding cylinder before the growth of a single crystal silicon rod.

[0015] In some embodiments of the present disclosure, the method further includes: controlling, by the mass flow controller, the temperatures of the cooling water in the plurality of water-cooling regions to gradually decrease and/or controlling the flow rates of the cooling water in the plurality of water-cooling regions to gradually increase along with the movement of the crucible in a direction close to the guiding cylinder during the growth of the single crystal silicon rod.

[0016] In some embodiments of the present disclosure, the method further includes: obtaining a defect evaluation result of the single crystal silicon rod after the growth of the single crystal silicon rod; and adjusting the flow rates and/or the temperatures of the cooling water in the water-cooling regions based on the defect evaluation result of the single crystal silicon rod.

[0017] In some embodiments of the present disclosure, the adjusting the flow rates and/or the temperatures of the cooling water in the water-cooling regions based on the defect evaluation result of the single crystal silicon rod includes: reducing the temperatures of the cooling water in the water-cooling regions and/or increase the flow rates of the cooling water in the water-cooling regions in a case that the single crystal silicon rod has a V-rich defect; and increasing the temperatures of the cooling water in the water-cooling regions and/or reduce the flow rates of the cooling water in the water-cooling regions in a case that the single crystal silicon rod has an N-rich defect.

[0018] The present disclosure has the following beneficial effects.

[0019] In the embodiments of the present disclosure, the water-cooling structure includes the plurality of water-cooling regions independent of each other, and the mass flow controller controls the flow rates and the temperatures of the cooling water in different water-cooling regions. During the growth of the single crystal silicon rod, the temperatures and the flow rates of the cooling water in different water-cooling regions are controlled on a regional basis, so it is able to reduce a change in a longitudinal temperature gradient during the growth of the crystal, achieve smooth transition

between the temperature regions, and provide a stable longitudinal temperature gradient of a thermal field, thereby to reduce the defects of the fabricated single crystal silicon.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] Fig. 1 is a schematic view showing a single crystal furnace according to an embodiment of the present disclosure; and

[0021] Fig. 2 is a flow chart of a method for fabricating single crystal silicon according to an embodiment of the present disclosure.

Reference Sign List

- | | |
|----|----------------------------|
| 1 | single crystal silicon rod |
| 2 | water-cooling structure |
| 3 | guiding cylinder |
| 4 | heater |
| 5 | graphite crucible |
| 6 | quartz crucible |
| 7 | silicon solution |
| 8 | crucible support assembly |
| 9 | mass flow controller |
| 10 | cooling water supply unit |

DETAILED DESCRIPTION

[0022] In order to make the objects, the technical solutions and the advantages of the present disclosure more apparent, the present disclosure will be described hereinafter in a clear and complete manner in conjunction with the drawings and embodiments. Obviously, the following embodiments merely relate to a part of, rather than all of, the embodiments of the present disclosure, and based on these embodiments, a person skilled in the art may, without any creative effort, obtain the other embodiments, which also fall within the scope of the present disclosure.

[0023] A defect property of the single crystal silicon rod depends sensitively on a growth condition and a cooling condition of a crystal, so types and distribution of defects formed during the growth may be controlled through adjusting a thermal environment in the vicinity of a growth interface.

[0024] The growth defects include vacancy-type defects and interstitial-type defects, and these defects are caused by the accumulation of vacancy point defects or interstitial point defects at a concentration greater than an equilibrium concentration. The formation of the growth defect is closely related to V/G , where V represents a growth speed, and G represents a temperature gradient of a crystal in the vicinity of a crystal growth interface. In a case that V/G is greater than a critical value, the vacancy-type defect is formed, and in a case that V/G is smaller than the critical value, the interstitial-type defect is formed. Hence, in a case that the crystal grows in a specific thermal region, a type, a size and density of the defect in the crystal are affected by a pulling speed. A cooling speed of the crystal is controlled to be between a solidification temperature and a temperature of about 1000 °C. Within this temperature range, in a case that molten silicon is solidified into single crystal silicon, a core of the defect is formed and grows during the heating process. Interstitial or vacancy of silicon is diffused toward a side surface of an ingot in this way, or accelerated to be linked to each other, so as to inhibit the oversaturation of the interstitial or vacancy to be smaller than a critical value for accumulation. A difference between temperatures of the regions for the ingot fabricated using a CZ method is minimized to be within a range of 1000 °C to 1100 °C. More specifically, in the region for the ingot having a temperature of 1000 °C to 1100 °C, a difference temperature for the single crystal silicon ingot is not greater than 20 °C/cm. Optionally, the temperature control difference occurs at a peripheral portion of the ingot in a vertical direction. In addition, in a case that the temperature of the ingot is 1000 °C to 1100 °C, a temperature for the growth of the ingot is controlled so that a temperature gradient between a central portion and the peripheral portion of the ingot is not greater than 1.5 °C/cm.

[0025] A water-cooling jacket is a key component of a single crystal furnace, and it is used to stabilize a longitudinal temperature gradient of a thermal field. However,

in the related art, the water-cooling jacket has a simple structure, and it is impossible to adjust a flow rate and a temperature of cooling water, so it is impossible to achieve a cooling effect to the greatest extent. At a melting stage, a crucible is located at a low level, and the water-cooling jacket is less affected by heat from the crucible, so the water-cooling jacket has a low temperature, the longitudinal temperature gradient of the thermal field is large, and volatile matters easily gather on the water-cooling jacket. Later in a single crystal constant-diameter stage, the crucible is located at a high level, the crystal is close to the water-cooling jacket, and the water-cooling jacket is affected by the heat from the crucible, so the temperature of the water-cooling jacket increases, and the longitudinal temperature gradient of the thermal field is small. In other words, due to a change in a position of the single crystal, the temperature of the water-cooling jacket is not constant, so the longitudinal temperature gradient of the thermal field is not stable, and it is impossible to ensure the stable growth of the single crystal. In addition, the water-cooling jacket is a component where the cooling water flows, and there is no measure to control the cooling water in the water-cooling jacket, so the cooling water is not fully utilized in the water-cooling jacket, and a majority of the cooling water is wasted. It is impossible for the cooling water to control the water-cooling jacket to be at a constant temperature, and control the longitudinal temperature gradient of the thermal field for the growth of the single crystal.

[0026] An object of the present disclosure is to provide a single crystal furnace and a method for fabricating single crystal silicon, so as to reduce defects of the fabricated single crystal silicon.

[0027] The present disclosure provides in some embodiments a single crystal furnace which, as shown in Fig. 1, includes a furnace body. A crucible support assembly 8 is arranged inside the furnace body, and a crucible is arranged on the crucible support assembly 8. The crucible includes a graphite crucible 5 and a quartz crucible 6 inside the graphite crucible 5, and a silicon solution 7 is received in the quartz crucible 6. A guiding cylinder 3 is arranged right above the crucible, a heater 4 is arranged between an inner wall of the furnace body and a periphery of the crucible, and a seed pulling mechanism is arranged at a top of the furnace body. The single crystal furnace further

includes: a water-cooling structure 2 arranged at a side of the guiding cylinder 3 away from the crucible support assembly 8, the water-cooling structure 2 including a plurality of water-cooling regions independent of each other, and the plurality of water-cooling regions being arranged sequentially in a direction away from the guiding cylinder 3; and a mass flow controller (MFC) 9 configured to control flow rates and temperatures of cooling water in different water-cooling regions.

[0028] In the embodiments of the present disclosure, the water-cooling structure 2 includes the plurality of water-cooling regions independent of each other, and the mass flow controller 9 controls the flow rates and the temperatures of the cooling water in different water-cooling regions. During the growth of a single crystal silicon rod 1, the temperatures and the flow rates of the cooling water in different water-cooling regions are controlled on a regional basis, so it is able to reduce a change in a longitudinal temperature gradient during the growth of a crystal, achieve smooth transition between the temperature regions, and provide a stable longitudinal temperature gradient of a thermal field, thereby to reduce the defects of the fabricated single crystal silicon.

[0029] In the embodiments of the present disclosure, the water-cooling structure 2 includes 2, 3 or more water-cooling regions independent of each other.

[0030] In the embodiments of the present disclosure, the mass flow controller 9 is coupled to a cooling water supply unit 10, so as to control the flow rates and temperatures of the cooling water in different water-cooling regions. Before the growth of the single crystal silicon rod 1, the mass flow controller 9 sets the flow rates and temperatures of the cooling water in different water-cooling regions. During the growth of the single crystal silicon rod 1, along with a change in a position of the single crystal silicon rod 1, the mass flow controller 9 may also adjust the flow rates and temperatures of the cooling water in different water-cooling regions, so as to stabilize the longitudinal temperature direction of the thermal field, thereby to reduce the defects of the fabricated single crystal silicon.

[0031] In the embodiments of the present disclosure, the mass flow controller 9 is configured to control the temperatures of the cooling water in the plurality of water-

cooling regions to gradually decrease and/or control the flow rates of the cooling water in the plurality of water-cooling regions to gradually increase in a direction away from the guiding cylinder 3 before the growth of the single crystal silicon rod 1, so as to stabilize the longitudinal temperature gradient of the thermal field. In the embodiments of the present disclosure, it is able to merely adjust the temperatures of the cooling water in the plurality of water-cooling regions, or merely adjust the flow rates of the cooling water in the plurality of water-cooling regions, or adjust both the temperatures and the flow rates the cooling water in the plurality of water-cooling regions. In a case that the temperature of the cooling water in the water-cooling region decreases, an ambient temperature in the vicinity of the water-cooling region may decrease, and in a case that the temperature of the cooling water in the water-cooling region increases, the ambient temperature in the vicinity of the water-cooling region may increase. In a case that the flow rate of the cooling water in the water-cooling region decreases, the ambient temperature in the vicinity of the water-cooling region may increase, and in a case that the flow rate of the cooling water in the water-cooling region increases, the ambient temperature in the vicinity of the water-cooling region may decrease.

[0032] In some embodiments of the present disclosure, as shown in Fig. 1, the water-cooling structure 2 includes 3 water-cooling regions independent of each other, i.e., region A, region B and region C. Before the growth of the single crystal silicon rod 1, the mass flow controller 9 controls the temperatures of the cooling water guided into the regions A, B and C to be different. The temperature of the cooling water in the region A is greater than the temperature of the cooling water in the region B, and the temperature of the cooling water in the region B is greater than the temperature of the cooling water in the region C. In this way, it is able to stabilize the longitudinal temperature gradient of the thermal field.

[0033] A difference between the temperatures of the adjacent water-cooling regions is 1.5 °C to 2.5 °C, e.g., 1.5 °C, 1.6 °C, 1.7 °C, 1.8 °C, 1.9 °C, 2.0 °C, 2.1 °C, 2.2 °C, 2.3 °C, 2.4 °C or 2.5 °C. Optionally, the difference between the temperatures of the adjacent water-cooling regions is 2.0 °C, so as to reduce the formation of the defects of the single crystal silicon rod 1.

[0034] Of course, the flow rate of the cooling water in the region A is further controlled to be smaller than the flow rate of the cooling water in the region B, and the flow rate of the cooling water in the region B is further controlled to be smaller than the flow rate of the cooling water in the region C, so as to further stabilize the longitudinal temperature gradient of the thermal field.

[0035] During the growth of the single crystal silicon rod 1, in a case that the single crystal silicon rod 1 is pulled by the seed pulling mechanism, the crucible moves upward gradually to be close to the water-cooling structure 2, and the water-cooling structure 2 is affected by the heat from the crucible. In order to ensure the stable longitudinal temperature gradient of the thermal field, the temperatures and the flow rates of the cooling water in the plurality of water-cooling regions need to be adjusted. To be specific, along with the movement of the crucible in the direction close to the guiding cylinder 3, the temperatures of the cooling water in the plurality of water-cooling regions decrease gradually, and/or the flow rates of the cooling water in the plurality of water-cooling regions increase gradually, so as to cancel out the influence caused by the heat from the crucible, thereby to stabilize the longitudinal temperature gradient of the thermal field.

[0036] The mass flow controller 9 may set in advance the flow rates and the temperatures in the regions A, B and C during the growth of the single crystal silicon rod 1 in a case that the single crystal silicon rod 1 is at different positions. For example, at position 1, the flow rate is L1 and the temperature is T1 in the region A; the flow rate is L2 and the temperature is T2 in the region B; and the flow rate is L3 and the temperature is T3 in the region C. At position 2, the flow rate is L4 and the temperature is T4 in the region A; the flow rate is L5 and the temperature is T5 in the region B; and the flow rate is L6 and the temperature is T6 in the region C. In a case that the single crystal silicon rod 1 moves to position 1, the flow rate is controlled to be L1 and the temperature is controlled to be T1 in the region A, the flow rate is controlled to be L2 and the temperature is controlled to be T2 in the region B, and the flow rate is controlled to be L3 and the temperature is controlled to be T3 in the region C. In a case that the single crystal silicon rod 1 moves to position 2, the flow rate is controlled to be L4 and the

temperature is controlled to be T4 in the region A, the flow rate is controlled to L5 and the temperature is controlled to be T5 in the region B, and the flow rate is controlled to be L6 and the temperature is controlled to be T6 in the region C.

[0037] In the embodiments of the present disclosure, it is able to merely adjust the temperatures of the cooling water in the plurality of water-cooling regions, or merely adjust the flow rates of the cooling water in the plurality of water-cooling regions, or adjust both the temperatures and the flow rates of the cooling water in the plurality of water-cooling regions.

[0038] In some embodiments of the present disclosure, the mass flow controller 9 is further configured to obtain a defect evaluation result of a single crystal silicon rod 1 after the growth of the single crystal silicon rod 1, and adjust the flow rates and/or the temperatures of the cooling water in the water-cooling regions based on the defect evaluation result of the single crystal silicon rod 1.

[0039] A defect property of the single crystal depends sensitively on a cooling condition of the crystal, and through adjusting a thermal environment in the vicinity of the growth interface, it is able to control the type and the distribution of the defect formed during the growth. Hence, after the growth of the single crystal silicon rod 1, the flow rates and/or the temperatures of the cooling water in the water-cooling regions may be adjusted based on the defect of the single crystal silicon rod 1, so as to control and optimize the longitudinal temperature gradient of the thermal field. Merely the temperatures of the cooling water in the plurality of water-cooling regions may be adjusted, or merely the flow rates of the cooling water in the plurality of water-cooling regions may be adjusted, or both the temperatures and the flow rates of the cooling water in the plurality of water-cooling regions may be adjusted.

[0040] In some embodiments of the present disclosure, the mass flow controller 9 is specifically configured to reduce the temperatures of the cooling water in the water-cooling regions and/or increase the flow rates of the cooling water in the water-cooling regions in a case that the single crystal silicon rod has a V-rich defect, and increase the temperatures of the cooling water in the water-cooling regions and/or reduce the flow

rates of the cooling water in the water-cooling regions in a case that the single crystal silicon rod has an N-rich defect.

[0041] In the case that the single crystal silicon rod 1 has the V-rich defect, it means that the ambient temperature of the growth interface of the single crystal silicon rod 1 is high, so the temperature of the cooling water in the water-cooling region is reduced and/or the flow rate of the cooling water in the water-cooling region is increased to reduce the ambient temperature of the growth interface of the single crystal silicon rod 1, so as to improve the V-rich defect. In a case that the single crystal silicon rod 1 has the N-rich defect, it means that the ambient temperature of the growth interface of the single crystal silicon rod 1 is low, so the temperature of the cooling water in the water-cooling region is increased and/or the flow rate of the cooling water in the water-cooling region is reduced to reduce the ambient temperature of the growth interface of the single crystal silicon rod 1, so as to improve the N-rich defect.

[0042] The present disclosure further provides in some embodiments a method for fabricating single crystal silicon, applied to the above-mentioned single crystal furnace, which includes: controlling, by the mass flow controller 9, the temperatures of the cooling water in the plurality of water-cooling regions to gradually decrease and/or controlling the flow rates of the cooling water in the plurality of water-cooling regions to gradually increase in a direction away from the guiding cylinder 3 before the growth of a single crystal silicon rod 1.

[0043] In the embodiments of the present disclosure, the water-cooling structure 2 includes the plurality of water-cooling regions independent of each other, and the mass flow controller 9 controls the flow rates and the temperatures of the cooling water in different water-cooling regions. During the growth of a single crystal silicon rod 1, the temperatures and the flow rates of the cooling water in different water-cooling regions are controlled on a regional basis, so it is able to reduce a change in a longitudinal temperature gradient during the growth of a crystal, achieve smooth transition between the temperature regions, and provide a stable longitudinal temperature gradient of a thermal field, thereby to reduce the defects of the fabricated single crystal silicon.

[0044] In the embodiments of the present disclosure, the mass flow controller 9 is coupled to a cooling water supply unit 10, so as to control the flow rates and temperatures of the cooling water in different water-cooling regions. Before the growth of the single crystal silicon rod 1, the mass flow controller 9 sets the flow rates and temperatures of the cooling water in different water-cooling regions. During the growth of the single crystal silicon rod 1, along with a change in a position of the single crystal silicon rod 1, the mass flow controller 9 may also adjust the flow rates and temperatures of the cooling water in different water-cooling regions, so as to stabilize the longitudinal temperature direction of the thermal field, thereby to reduce the defects of the fabricated single crystal silicon.

[0045] In the embodiments of the present disclosure, the mass flow controller 9 is configured to control the temperatures of the cooling water in the plurality of water-cooling regions to gradually decrease and/or control the flow rates of the cooling water in the plurality of water-cooling regions to gradually increase in a direction away from the guiding cylinder 3 before the growth of the single crystal silicon rod 1, so as to stabilize the longitudinal temperature gradient of the thermal field. In the embodiments of the present disclosure, it is able to merely adjust the temperatures of the cooling water in the plurality of water-cooling regions, or merely adjust the flow rates of the cooling water in the plurality of water-cooling regions, or adjust both the temperatures and the flow rates the cooling water in the plurality of water-cooling regions.

[0046] In some embodiments of the present disclosure, the method further includes: controlling, by the mass flow controller, the temperatures of the cooling water in the plurality of water-cooling regions to gradually decrease and/or controlling the flow rates of the cooling water in the plurality of water-cooling regions to gradually increase along with the movement of the crucible in a direction close to the guiding cylinder during the growth of the single crystal silicon rod.

[0047] During the growth of the single crystal silicon rod 1, in a case that the single crystal silicon rod 1 is pulled by the seed pulling mechanism, the crucible moves upward gradually to be close to the water-cooling structure 2, and the water-cooling structure 2 is affected by the heat from the crucible. In order to ensure the stable

longitudinal temperature gradient of the thermal field, the temperatures and the flow rates of the cooling water in the plurality of water-cooling regions need to be adjusted. To be specific, along with the movement of the crucible in the direction close to the guiding cylinder 3, the temperatures of the cooling water in the plurality of water-cooling regions decrease gradually, and/or the flow rates of the cooling water in the plurality of water-cooling regions increase gradually, so as to cancel out the influence caused by the heat from the crucible, thereby to stabilize the longitudinal temperature gradient of the thermal field.

[0048] In the embodiments of the present disclosure, it is able to merely adjust the temperatures of the cooling water in the plurality of water-cooling regions, or merely adjust the flow rates of the cooling water in the plurality of water-cooling regions, or adjust both the temperatures and the flow rates of the cooling water in the plurality of water-cooling regions.

[0049] In some embodiments of the present disclosure, as shown in Fig. 2, the method further includes: Step 101 of obtaining a defect evaluation result of the single crystal silicon rod after the growth of the single crystal silicon rod; and Step 102 of adjusting the flow rates and/or the temperatures of the cooling water in the water-cooling regions based on the defect evaluation result of the single crystal silicon rod.

[0050] A defect property of the single crystal depends sensitively on a cooling condition of the crystal, and through adjusting a thermal environment in the vicinity of the growth interface, it is able to control the type and the distribution of the defect formed during the growth. Hence, after the growth of the single crystal silicon rod 1, the flow rates and/or the temperatures of the cooling water in the water-cooling regions may be adjusted based on the defect of the single crystal silicon rod 1, so as to control and optimize the longitudinal temperature gradient of the thermal field. Merely the temperatures of the cooling water in the plurality of water-cooling regions may be adjusted, or merely the flow rates of the cooling water in the plurality of water-cooling regions may be adjusted, or both the temperatures and the flow rates of the cooling water in the plurality of water-cooling regions may be adjusted.

[0051] In some embodiments of the present disclosure, the adjusting the flow rates and/or the temperatures of the cooling water in the water-cooling regions based on the defect evaluation result of the single crystal silicon rod includes: reducing the temperatures of the cooling water in the water-cooling regions and/or increase the flow rates of the cooling water in the water-cooling regions in a case that the single crystal silicon rod has a V-rich defect; and increasing the temperatures of the cooling water in the water-cooling regions and/or reduce the flow rates of the cooling water in the water-cooling regions in a case that the single crystal silicon rod has an N-rich defect.

[0052] In the case that the single crystal silicon rod 1 has the V-rich defect, it means that the ambient temperature of the growth interface of the single crystal silicon rod 1 is high, so the temperature of the cooling water in the water-cooling region is reduced and/or the flow rate of the cooling water in the water-cooling region is increased to reduce the ambient temperature of the growth interface of the single crystal silicon rod 1, so as to improve the V-rich defect. In a case that the single crystal silicon rod 1 has the N-rich defect, it means that the ambient temperature of the growth interface of the single crystal silicon rod 1 is low, so the temperature of the cooling water in the water-cooling region is increased and/or the flow rate of the cooling water in the water-cooling region is reduced to reduce the ambient temperature of the growth interface of the single crystal silicon rod 1, so as to improve the N-rich defect.

[0053] It should be further appreciated that, the above embodiments have been described in a progressive manner, and the same or similar contents in the embodiments have not been repeated, i.e., each embodiment has merely focused on the difference from the others. Especially, the method embodiments are substantially similar to the product embodiments, and thus have been described in a simple manner.

[0054] Unless otherwise defined, any technical or scientific term used herein shall have the common meaning understood by a person of ordinary skills. Such words as “first” and “second” used in the specification and claims are merely used to differentiate different components rather than to represent any order, number or importance. Similarly, such words as “one” or “one of” are merely used to represent the existence of at least one member, rather than to limit the number thereof. Such words

as “include” or “including” intends to indicate that an element or object before the word contains an element or object or equivalents thereof listed after the word, without excluding any other element or object. Such words as “connect/connected to” or “couple/coupled to” may include electrical connection, direct or indirect, rather than to be limited to physical or mechanical connection. Such words as “on”, “under”, “left” and “right” are merely used to represent relative position relationship, and when an absolute position of the object is changed, the relative position relationship will be changed too.

[0055] It should be appreciated that, in the case that such an element as layer, film, region or substrate is arranged “on” or “under” another element, it may be directly arranged “on” or “under” the other element, or an intermediate element may be arranged therebetween.

[0056] In the above description, the features, structures, materials or characteristics may be combined in any embodiment or embodiments in an appropriate manner.

[0057] 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 single crystal furnace, comprising a furnace body, wherein a crucible support assembly is arranged inside the furnace body, a crucible is arranged on the crucible support assembly, a guiding cylinder is arranged right above the crucible, a heater is arranged between an inner wall of the furnace body and a periphery of the crucible, and a seed pulling mechanism is arranged at a top of the furnace body, wherein the single crystal furnace further comprises:

a water-cooling structure arranged at a side of the guiding cylinder away from the crucible support assembly, wherein the water-cooling structure comprises a plurality of water-cooling regions independent of each other, and the plurality of water-cooling regions is arranged sequentially in a direction away from the guiding cylinder; and

a mass flow controller configured to control flow rates and temperatures of cooling water in different water-cooling regions.

2. The single crystal furnace according to claim 1, wherein the mass flow controller is specifically configured to control the temperatures of the cooling water in the plurality of water-cooling regions to gradually decrease and/or control the flow rates of the cooling water in the plurality of water-cooling regions to gradually increase in a direction away from the guiding cylinder before the growth of a single crystal silicon rod.

3. The single crystal furnace according to claim 2, wherein a difference between the temperatures in adjacent water-cooling regions is 1.5°C to 2.5°C.

4. The single crystal furnace according to claim 1, wherein the mass flow controller is specifically configured to control the temperatures of the cooling water in the plurality of water-cooling regions to gradually decrease and/or control the flow rates of the cooling water in the plurality of water-cooling regions to gradually increase along

with the movement of the crucible in a direction close to the guiding cylinder during the growth of the single crystal silicon rod.

5. The single crystal furnace according to claim 1, wherein the mass flow controller is further configured to obtain a defect evaluation result of a single crystal silicon rod after the growth of the single crystal silicon rod, and adjust the flow rates and/or the temperatures of the cooling water in the water-cooling regions based on the defect evaluation result of the single crystal silicon rod.

6. The single crystal furnace according to claim 5, wherein the mass flow controller is specifically configured to reduce the temperatures of the cooling water in the water-cooling regions and/or increase the flow rates of the cooling water in the water-cooling regions in a case that the single crystal silicon rod has a V-rich defect, and increase the temperatures of the cooling water in the water-cooling regions and/or reduce the flow rates of the cooling water in the water-cooling regions in a case that the single crystal silicon rod has a N-rich defect.

7. The single crystal furnace according to claim 1, wherein the water-cooling structure comprises three water-cooling regions.

8. A method for fabricating single crystal silicon, applied to the single crystal furnace according to any one of claims 1 to 7, comprising:

controlling, by the mass flow controller, the temperatures of the cooling water in the plurality of water-cooling regions to gradually decrease and/or controlling the flow rates of the cooling water in the plurality of water-cooling regions to gradually increase in a direction away from the guiding cylinder before the growth of a single crystal silicon rod.

9. The method according to claim 8, further comprising:

controlling, by the mass flow controller, the temperatures of the cooling water in the plurality of water-cooling regions to gradually decrease and/or controlling the flow rates of the cooling water in the plurality of water-cooling regions to gradually increase along with the movement of the crucible in a direction close to the guiding cylinder during the growth of the single crystal silicon rod.

10. The method according to claim 8, further comprising:

obtaining a defect evaluation result of the single crystal silicon rod after the growth of the single crystal silicon rod; and

adjusting the flow rates and/or the temperatures of the cooling water in the water-cooling regions based on the defect evaluation result of the single crystal silicon rod.

11. The method according to claim 10, wherein the adjusting the flow rates and/or the temperatures of the cooling water in the water-cooling regions based on the defect evaluation result of the single crystal silicon rod comprises:

reducing the temperatures of the cooling water in the water-cooling regions and/or increase the flow rates of the cooling water in the water-cooling regions in a case that the single crystal silicon rod has a V-rich defect; and

increasing the temperatures of the cooling water in the water-cooling regions and/or reduce the flow rates of the cooling water in the water-cooling regions in a case that the single crystal silicon rod has a N-rich defect.