

CRYSTAL INGOT GROWTH METHOD AND CRYSTAL INGOT GROWTH APPARATUS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present disclosure claims a priority of Chinese Patent Application No. 202310707576.0 filed in China on June 14, 2023, the entire contents of which are hereby incorporated by reference in their entireties.

TECHNICAL FIELD

[0002] The present disclosure relates to the field of semiconductor product manufacturing, and in particular, to a crystal ingot growth method and a crystal ingot growth apparatus.

BACKGROUND

[0003] Oxygen is a critical indicator in the quality evaluation of pulled crystal ingots. The radial oxygen gradient (ROG) has a significant impact on yield of a semiconductor device. Meanwhile, oxygen can also form bulk micro defects (BMD) precipitates within the wafer body. These BMD precipitates have an internal gettering effect, which can effectively absorb and capture defects on the wafer surface, thereby forming a defect-free zone in proximity to the wafer surface. This is very helpful for circuit etching of chips and can greatly improve the yield of semiconductor device products. However, the crystal pulling process or the crystal ingot growth process is an extremely complex process of directional solidification, with its complexity primarily arising from an uncertain convection within the melt. Due to the high uncertainty of convection, both the precipitated oxygen in the melt and the oxygen incorporated into the crystal ingot exhibit uncertainty. At the same time, the uncertain convection leads to instability of the solid-liquid interface of the crystal ingot, which may result in an unstable crystal pulling. Slight fluctuations can lead to crystal defects within the ingot, while large

fluctuations may even cause the ingot to lose its single crystal properties, resulting in losses (LOSS).

SUMMARY

[0004] To solve the above-mentioned technical problem, the present disclosure provides a crystal ingot growth method and a crystal ingot growth apparatus, which can address the problem of uncertainty in silicon melt convection that affects the uniformity of oxygen in the crystal ingot.

[0005] An embodiment of the present disclosure provides a crystal ingot growth method, wherein a single crystal furnace is used for crystal ingot growth and the single crystal furnace comprises a crucible for containing a silicon melt, and the method includes the following steps:

[0006] dipping a seed crystal into the silicon melt to form a crystal ingot, and applying a horizontal magnetic field having a magnetic field strength of a first preset value, wherein, in an axial direction of the crystal ingot, a first distance between a maximum Gauss plane of the horizontal magnetic field and a liquid surface of the silicon melt is less than a second preset value;

[0007] during a body process of the crystal ingot growth, applying a cusp magnetic field having a magnetic field strength of a third preset value, wherein a zero Gauss plane of the cusp magnetic field is located at an R-arc part of the crucible.

[0008] Optionally, the crystal ingot growth method further comprises:

[0009] during a shoulder process of a growth of the crystal ingot that has completed a dip process, and prior to entering the body process, increasing the strength of the horizontal magnetic field from the first preset value to a fourth preset value.

[0010] Optionally, during a shoulder process of a growth of the crystal ingot that has completed dip process, and when a diameter of the crystal ingot is greater than or equal to 80% of a target constant diameter length, increasing the strength of the horizontal magnetic field to the fourth preset value .

[0011] Optionally, the step of applying a cusp magnetic field having a magnetic field strength of a third preset value, comprises:

[0012] simultaneously with applying the cusp magnetic field, increasing the strength of the horizontal magnetic field from the fourth preset value to a fifth preset value.

[0013] Optionally, the first preset value is 1100-1300 Gauss, the fourth preset value is 1450-1550 Gauss, and the fifth preset value is 2100-2300 Gauss.

[0014] Optionally, the third preset value is 1400-1600 Gauss.

[0015] Optionally, the crystal ingot growth method further includes:

[0016] adjusting a position of the maximum Gauss plane to ensure that the first distance remains consistently less than the first preset value during the crystal ingot growth.

[0017] Optionally, the crystal ingot growth method further includes:

[0018] adjusting a position of the zero Gauss plane to ensure that the position of the zero Gauss plane remains consistently located at the R-arc part of the crucible during the crystal ingot growth.

[0019] An embodiment of the present disclosure also provides a crystal ingot growth apparatus, which includes:

[0020] a furnace body;

[0021] a crucible, located within the furnace body, containing a silicon melt;

[0022] a horizontal magnetic field generating structure, arranged on the periphery of the furnace body, configured to output a horizontal magnetic field to the crucible;

[0023] a cusp magnetic field generating structure, arranged on the periphery of the furnace body, configured to output a cusp magnetic field to the crucible, wherein the cusp magnetic field generating structure is located on the side of the horizontal magnetic field generating structure that is away from the top of the furnace body.

[0024] Optionally, the crystal ingot growth apparatus further includes:

[0025] a first adjustment structure, configured to control a movement of the horizontal magnetic field generating structure in an axial direction of the crystal ingot, so that during the crystal ingot growth, a distance between a maximum Gauss plane of the

horizontal magnetic field and a liquid surface of the silicon melt is less than a first preset value;

[0026] a second adjustment structure, configured to control a movement of the cusp magnetic field generating structure in an axial direction of the crystal ingot, so that during the crystal ingot growth, a zero Gauss plane of the cusp magnetic field is always at an R-arc part of the crucible.

[0027] The beneficial effects of the present disclosure are as follows: by applying the horizontal magnetic field during the dip process and keeping the distance between the maximum Gauss plane and the surface of the silicon melt in the axial direction of the crystal ingot less than the second preset value, convection in the silicon melt can be suppressed, oxygen evaporation can be inhibited, and the stability of the solid-liquid interface can be improved. This effectively addresses the problem of uncertainty in precipitated oxygen in the melt and oxygen incorporated into the crystal ingot caused by convection uncertainty in the silicon melt, thereby improving the quality of the crystal ingot.

[0028] During the body process, by applying the cusp magnetic field and keeping its zero Gauss plane at the R-arc part of the crucible, oxygen precipitation can be promoted. The cusp magnetic field cooperates with the horizontal magnetic field so that oxygen can effectively and uniformly incorporate into the crystal ingot.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] FIG. 1 is a schematic flow chart of a crystal ingot growth method according to an embodiment of the present disclosure;

[0030] FIG. 2 is a first schematic diagram of a crystal ingot growth apparatus according to an embodiment of the present disclosure; and

[0031] FIG. 3 is a second schematic diagram of a crystal ingot growth apparatus according to an embodiment of the present disclosure.

DETAILED DESCRIPTION OF EMBODIMENTS

[0032] In order to make an objective, a technical solution and advantages of the present disclosure clearer, the technical solutions of the embodiments of the present disclosure will be clearly and completely described below in conjunction with the accompanying drawings of the embodiments. Obviously, the described embodiments are only parts of the embodiments of the present disclosure, rather than all of them. All other embodiments obtained by those skilled in the art based on the described embodiments of the present disclosure without creative efforts shall fall within the protection scope of the present disclosure.

[0033] Unless otherwise defined, technical or scientific terms used in the present disclosure shall have the ordinary meaning understood by those skilled in the art to which the present disclosure belongs. The terms “first”, “second” and the like used herein do not indicate any order, quantity, or importance, but are merely used to distinguish different components. Similarly, the terms “a”, “an” or “the” and the like do not imply limitation on quantity, but rather indicate the presence of at least one. The terms “comprising”, “including” and the like mean that the element or object preceding the term covers the elements or objects listed after the term and their equivalents, without excluding other elements or objects. The terms “connected”, “coupled” and the like are not limited to physical or mechanical connections, but may include electrical connections, whether direct or indirect. The terms “up”, “down” “left”, “right” etc., are merely used to indicate relative positional relationships, and when the absolute position of the described object changes, the relative positional relationships may also change accordingly.

[0034] Referring to FIGS. 1-3, one embodiment of the present disclosure provides a crystal ingot growth method, in which a single crystal furnace is used for crystal ingot growth and the single crystal furnace includes a crucible for containing a silicon melt, and the method includes the following steps:

[0035] dipping a seed crystal into the silicon melt to form a crystal ingot 1, and applying a horizontal magnetic field with a magnetic field strength of a first preset value, where in an axial direction of the crystal ingot, a first distance between a maximum

Gauss plane 5 of the horizontal magnetic field and a liquid surface of the silicon melt is less than a second preset value;

[0036] during a body process of the crystal ingot growth, applying a cusp magnetic field with a magnetic field strength of a third preset value, where a zero Gauss plane 7 of the cusp magnetic field is located at an R-arc part of the crucible.

[0037] At an initial stage of the crystal ingot growth, the horizontal magnetic field is applied, and the first distance between the maximum Gauss plane 5 (MGP) of the horizontal magnetic field and the surface of the silicon melt in the axial direction of the crystal ingot is set to be less than the second preset value. By applying the horizontal magnetic field, convection in the silicon melt can be suppressed, oxygen evaporation can be inhibited. This alleviates the problem of uncertainty in precipitated oxygen in the melt and oxygen incorporated into the crystal ingot caused by convection uncertainty in the silicon melt, improves the stability of the solid-liquid interface, and prevents the crystal ingot from losing its single crystal properties due to large fluctuations.

[0038] It is to be noted that, in one embodiment, the first preset value is 1100-1300 Gauss, with a specific example being 1200 Gauss, which, while suppressing the convection in the silicon melt, avoids excessive magnetic field strength that could otherwise lead to a decrease in temperature inside the furnace and consequently affect the pulling of the crystal ingot, but is not limited thereto.

[0039] It is to be noted that, in some embodiments, the third preset value is 1400-1600 Gauss, preferably 1500 Gauss, but is not limited thereto.

[0040] It is to be noted that the second preset value is 2-3 mm, but is not limited thereto.

[0041] In some embodiments, in order to effectively suppress the convection in the silicon melt and improve the stability of the solid-liquid interface, the maximum Gauss plane 5 coincides with the surface of the silicon melt.

[0042] In an exemplary embodiment, the crystal ingot growth method further includes:

[0043] during a shoulder process of a growth of the crystal ingot that has completed a dip process and prior to entering the body process, increasing the strength of the horizontal magnetic field from the first preset value to a fourth preset value.

[0044] Since the crystal ingot growth conditions may vary in different crystal pulling stages, the strength of the horizontal magnetic field can be correspondingly adjusted according to actual needs, so as to effectively suppress the convection in the silicon melt.

[0045] By increasing the strength of the horizontal magnetic field from the first preset value to the fourth preset value before entering the body process, the stability of the solid-liquid interface can be improved, thereby enhancing the stability of the crystal ingot.

[0046] In some embodiments, the fourth preset value is 1450-1550 Gauss, optionally 1500 Gauss, but is not limited thereto.

[0047] It is to be noted that, in the above steps, it is sufficient that the strength of the horizontal magnetic field is increased from the first preset value to the fourth preset value before entering the body process; and as for the specific time point for increasing the strength of the horizontal magnetic field from the first preset value to the fourth preset value, it can be set according to actual needs.

[0048] In an exemplary embodiment, during a shoulder process of a growth of the crystal ingot that has completed a dip process and when a diameter of the crystal ingot is greater than or equal to 80% of a target constant diameter length, the strength of the horizontal magnetic field is increased to the fourth preset value, but is not limited thereto.

[0049] In an exemplary embodiment, the step of applying a cusp magnetic field with a magnetic field strength of a third preset value, comprises:

[0050] simultaneously with applying the cusp magnetic field, increasing the strength of the horizontal magnetic field from the fourth preset value to a fifth preset value.

[0051] Upon entering the body process, in order to effectively suppress convection, the magnetic field strength of the horizontal magnetic field needs to be further enhanced.

[0052] Exemplarily, the fifth preset value is 2100-2300 Gauss, optionally 2200 Gauss, but is not limited thereto.

[0053] In a specific embodiment, the crystal growth method includes the following steps:

[0054] dipping a seed crystal into the silicon melt to form a crystal ingot, applying a horizontal magnetic field with a magnetic field strength of 1200 Gauss, where the maximum Gauss plane 5 of the horizontal magnetic field coincides with the surface of the silicon melt;

[0055] during a shoulder process of a growth of the crystal ingot that has completed a dip process, increasing the strength of the horizontal magnetic field to 1500 Gauss when a diameter of the crystal ingot is greater than or equal to 80% of a target constant diameter length;

[0056] during the body process of the crystal ingot growth, applying a cusp magnetic field with a magnetic field strength of 1500 Gauss, wherein the zero Gauss plane 7 (ZGP) of the cusp magnetic field is located at the R-arc part of the crucible, while simultaneously increasing the strength of the horizontal magnetic field to 2200 Gauss.

[0057] It is to be noted that the horizontal magnetic field and the cusp magnetic field do not interfere with one another, so as to avoid affecting the positions of the maximum Gauss plane 5 and the zero Gauss plane 7, thereby avoiding affecting the oxygen uniformity of the crystal ingot.

[0058] In an exemplary embodiment, the crystal ingot growth method further includes:

[0059] adjusting a position of the maximum Gauss plane 5 to ensure that the first distance remains consistently less than the first preset value during the crystal ingot growth.

[0060] In order to ensure the suppression effect of the horizontal magnetic field on the convection in the silicon melt, during the crystal ingot growth, the distance between the maximum Gauss plane 5 of the horizontal magnetic field and the surface of the silicon melt in the axial direction of the crystal ingot shall always be kept less than the first preset value. Optionally, during the crystal ingot growth, the distance between the

maximum Gauss plane 5 of the horizontal magnetic field and the surface of the silicon melt in the axial direction of the crystal ingot shall always be kept at zero, i.e., the maximum Gauss plane 5 of the horizontal magnetic field coincides with the surface of the silicon melt.

[0061] To ensure that the maximum Gauss plane 5 coincides with the surface of the silicon melt, it is necessary to determine the distance between the maximum Gauss plane 5 and the surface of the silicon melt. The process of adjusting the relative positional relationship between the maximum Gauss plane 5 and the surface of the silicon melt is specifically described below.

[0062] Referring to FIG. 3, a second distance b between a first position of the furnace body and the surface of the silicon melt in the axial direction of the crystal ingot is determined;

[0063] based on the second distance b , the first distance c (i.e., the distance between the maximum Gauss plane 5 and the surface of the silicon melt in the axial direction of the crystal ingot) is determined, where $c=a+d-b$. Here, 'a' is the distance between a first end face of the horizontal magnetic field generating structure (where, the horizontal magnetic field generating structure is located at the periphery of the furnace body, used for providing a horizontal magnetic field to the crucible, and the end face of the horizontal magnetic field generating structure that is away from the silicon melt is the first end face) and the first position in the axial direction of the crystal ingot, and 'd' is the distance between the first end face and the maximum Gauss plane 5 of the magnetic field in the axial direction of the crystal ingot.

[0064] When c is not zero, the horizontal magnetic field generating structure is controlled to move in the axial direction of the crystal ingot, thereby enabling the maximum Gauss plane 5 to coincide with the surface of the silicon melt.

[0065] Exemplarily, when c is greater than zero, it indicates that the maximum Gauss plane 5 is located above the surface of the silicon melt. In this case, the horizontal magnetic field generating structure can be controlled to move along the axial direction of the crystal ingot, in a direction towards the silicon melt. When c is less than zero, it

indicates that the maximum Gauss plane 5 is located below the silicon melt, and the horizontal magnetic field generating structure can be controlled to move along the axial direction of the crystal ingot, in a direction away from the silicon melt. Alternatively, when c is greater than zero, it indicates that the maximum Gauss plane 5 is located below the surface of the silicon melt, and the horizontal magnetic field generating structure can be controlled to move along the axial direction of the crystal ingot, in a direction away from the silicon melt. When c is less than zero, it indicates that the maximum Gauss plane 5 is located above the silicon melt, and the horizontal magnetic field generating structure can be controlled to move along the axial direction of the crystal ingot, in a direction towards the silicon melt.

[0066] In an exemplary embodiment, the crystal ingot growth method further includes:

[0067] adjusting a position of the zero Gauss plane 7 to ensure that the position of the zero Gauss plane 7 remains consistently located at the R-arc part of the crucible during the crystal ingot growth.

[0068] According to different oxygen content specifications of a target crystal ingot, the relative position of the zero Gauss plane 7 of the cusp magnetic field with respect to the R-arc part, as well as the strength of the cusp magnetic field (where increased the magnetic field strength correlates with greater oxygen precipitation), can be adjusted correspondingly to control the effective precipitation of oxygen.

[0069] During the crystal ingot growth, with the crystal ingot being lifted, the crucible will rise. In order to ensure that the zero Gauss plane 7 of the cusp magnetic field is always located at the R-arc part, the cusp magnetic field generating structure for generating the cusp magnetic field and the crucible can move synchronously. In other words, it is only necessary to determine the initial position of the zero Gauss plane 7 based on the R-arc part of the crucible.

[0070] The crucible is supported and fixed by a crucible shaft at its bottom. Assuming an initial length of the crucible shaft is h , a length of the R-arc part in the axial direction of the crystal ingot is g , a distance between a second end face of the cusp magnetic field generating structure (which is away from the horizontal magnetic field generating

structure) and the zero Gauss plane 7 is k, and the distance between the bottom of the furnace body and the second end face is j, then for the zero Gauss plane 7 to be located at the R-arc part, $h < k + j < g + h$ is required.

[0071] Referring to FIGS. 2 and 3 (FIG. 3 illustrates a crystal ingot 1), the crystal ingot growth method in this embodiment is implemented by a crystal ingot growth apparatus, where the crystal ingot growth apparatus includes:

[0072] a furnace body;

[0073] a crucible 9 located within the furnace body, where the crucible 9 contains a silicon melt;

[0074] a reflector 3 located above the silicon melt;

[0075] a water-cooling jacket 2 located at a side of the reflector 3 away from the silicon melt;

[0076] a horizontal magnetic field generating structure 4 arranged on a periphery of the furnace body and used to output a horizontal magnetic field to the crucible 9;

[0077] a cusp magnetic field generating structure 6 arranged on the periphery of the furnace body and used to output a cusp magnetic field to the crucible 9, where the cusp magnetic field generating structure 6 is located at a side of the horizontal magnetic field generating structure 4 that is away from the top of the furnace body.

[0078] a seed crystal lifting structure used to control the seed crystal 12 to move up and down in a first direction (i.e., an axial direction of the furnace body);

[0079] a first sensing structure 13 arranged on the furnace body and located at a first position of the furnace body in the first direction, used to emit a first signal when the seed crystal lifting structure controls the seed crystal to descend past the first position; where the second position is a position flush with the surface 8 of the silicon melt;

[0080] a second sensing structure arranged on the furnace body, and used to emit a second signal when the seed crystal lifting structure controls the seed crystal to descend to a second position;

[0081] a processing structure used to obtain a second distance b between the first position and the second position in the first direction based on the first signal and the

second signal, and to obtain a first distance c based on the second distance b , where $c=a+d-b$, where 'a' is the distance between the first end face and the first position in the first direction, and 'd' is the distance between the first end face and the maximum Gauss plane 5 of the magnetic field in the first direction;

[0082] a first adjustment structure used to control movement of the horizontal magnetic field generating structure in the axial direction of the crystal ingot based on the feedback from the processing structure, enabling the distance between the maximum Gauss plane 5 of the horizontal magnetic field and the surface of the silicon melt to be less than the first preset value during the crystal ingot growth.

[0083] Through the arrangement of the first sensing structure and the second sensing structure, information such as time and speed when the seed crystal passes through the first position and the second position during its descent are recorded respectively, thereby obtaining the second distance b between these two positions in the first direction. The distance 'a' between the first end face and the first position can be obtained by direct measurement. Since the position of the magnetic field generating structure is fixed, the maximum Gauss plane is fixed. The distance 'd' between the first end face and the maximum Gauss plane 5 of the magnetic field in the first direction can be obtained based on the first end face of the magnetic field generating structure. In this way, the distance MP between the maximum Gauss plane and the silicon melt can be obtained as $MP=a+d-b$. By adopting the above solution, the distance MP between the maximum Gauss plane and the silicon melt can be obtained, thereby improving the accuracy of this parameter in a straightforward and efficient manner.

[0084] The first sensing structure can have various specific structural forms. In an exemplary embodiment, the first sensing structure includes a through-beam sensor, where a signal emitting part and a signal receiving part of the through-beam sensor are located on opposite sides of the furnace body.

[0085] The positions of both the signal emitting part and the signal receiving part in the first direction are located at the first position, so that the first signal can be accurately emitted when the seed crystal passes the first position.

[0086] The mounting position of the through-beam sensor can be set according to actual needs, i.e., the first position can be set according to actual needs, as long as it is located above the crucible within the furnace body. In an exemplary embodiment, the furnace body includes a main body and a cover, and the signal emitting part and the signal receiving part are located at opposite sides of the cover.

[0087] The through-beam sensor can be mounted on an outer surface of the cover, thereby avoiding affecting components inside the furnace body.

[0088] The second sensing structure can have various specific structural forms, as long as it can emit the second signal when the seed crystal contacts the surface of the silicon melt. In an exemplary embodiment, the second sensing structure includes a current detection element, where one end of the current detection element is connected to the seed crystal lifting structure, and the other end of the current detection element is immersed in the silicon melt. The second sensing structure is used for emitting the second signal when the seed crystal lifting structure controls the seed crystal to descend until the seed crystal contacts the silicon melt.

[0089] When the tip of the seed crystal contacts the surface of the silicon melt, a circuit is formed between the seed crystal lifting structure and the silicon melt, resulting in a change in resistance, which consequently results in a variation in current. The processing structure receives the second signal and obtains the distance between the first position and the second position in the first direction based on the first signal.

[0090] It is to be noted that the second sensing structure may further include a monitoring element, used to monitor changes in the current detection element in real-time. When a change in the current of the current detection element is detected, the monitoring element emits the second signal, which is not limited thereto.

[0091] The monitoring element may include a switching circuit and a position information obtaining structure. When the tip of the seed crystal contacts the surface of the silicon melt, a circuit is formed between the seed crystal lifting structure and the silicon melt, resulting in a change in resistance, which consequently results in a variation in current. The switching circuit closes, thereby emitting a signal to the

position information obtaining structure, enabling the position information obtaining structure to obtain the distance between the first position and the second position based on information such as the moving speed of the seed crystal and the time required to move from the first position to the second position, but is not limited thereto.

[0092] In an exemplary embodiment, the seed crystal lifting structure includes a seed crystal chuck 11 and a seed crystal 12 fixed on the seed crystal chuck 11, where one end of the current detection element is connected to the seed crystal chuck 11. In an exemplary embodiment, the crucible 9 includes a quartz crucible and a graphite crucible located periphery of the quartz crucible, where the bottom of the graphite crucible is supported by a crucible shaft 10.

[0093] In an exemplary embodiment, a crucible tray is provided between the graphite crucible and the crucible shaft.

[0094] In an exemplary embodiment, the crystal ingot growth apparatus further includes:

[0095] a first adjustment structure used to control a movement of the horizontal magnetic field generating structure in an axial direction of the crystal ingot based on the feedback from the processing structure, so that during the crystal ingot growth, a distance between a maximum Gauss plane 5 of the horizontal magnetic field and a liquid surface of the silicon melt remains less than a first preset value;

[0096] a second adjustment structure used to control a movement of the cusp magnetic field generating structure in the axial direction of the crystal ingot, so that during the crystal ingot growth, a zero Gauss plane of the cusp magnetic field always remains at an R-arc part of the crucible.

[0097] Specifically, the second adjustment structure is used for controlling the cusp magnetic field generating structure to move up and down synchronously with the crucible, so that the zero Gauss plane 7 of the cusp magnetic field is always located at the R-arc part of the crucible.

[0098] It is to be understood that the above embodiments are merely exemplary embodiments adopted for illustrating the principles of the present disclosure, and the

present disclosure is not limited thereto. A person of ordinary skills in the art can make various modifications and variations to the present disclosure without departing from the spirit and scope of the present disclosure, and these modifications and variations shall also be considered within the protection scope of the present disclosure.

What is claimed is:

1. A crystal ingot growth method in which a single crystal furnace is used for crystal ingot growth and the single crystal furnace comprises a crucible for containing a silicon melt, comprising:

dipping a seed crystal into a silicon melt to form a crystal ingot, and applying a horizontal magnetic field with a magnetic field strength of a first preset value; wherein, in an axial direction of the crystal ingot, a first distance between a maximum gauss plane of the horizontal magnetic field and a liquid surface of the silicon melt is less than a second preset value;

during a body process of the crystal ingot growth, applying a cusp magnetic field with a magnetic field strength of a third preset value; wherein a zero gauss plane of the cusp magnetic field is located at an R-arc part of the crucible.

2. The crystal ingot growth method according to claim 1, further comprising:

during a shoulder process of a growth of the crystal ingot that has completed a dip process and prior to entering the body process, increasing the strength of the horizontal magnetic field from the first preset value to a fourth preset value.

3. The crystal ingot growth method according to claim 2, further comprising: during a shoulder process of a growth of the crystal ingot that has completed a dip process, and when a diameter of the crystal ingot is greater than or equal to 80% of a target constant diameter length, increasing the strength of the horizontal magnetic field to the fourth preset value.

4. The crystal ingot growth method according to claim 2, wherein the applying a cusp magnetic field with a magnetic field strength of a third preset value, comprises:

simultaneously with applying the cusp magnetic field, increasing the strength of the horizontal magnetic field from the fourth preset value to a fifth preset value.

5. The crystal ingot growth method according to claim 4, wherein the first preset value is 1100 Gauss to 1300 Gauss, the fourth preset value is 1450 Gauss to 1550 Gauss, and the fifth preset value is 2100 Gauss to 2300 Gauss.

6. The crystal ingot growth method according to claim 1, wherein the third preset value is 1400 Gauss to 1600 Gauss.

7. The crystal ingot growth method according to claim 1, further comprising:
adjusting a position of the maximum Gauss plane to ensure that the first distance remains consistently less than the first preset value during the crystal ingot growth.

8. The crystal ingot growth method according to claim 1, further comprising:
adjusting a position of the zero Gauss plane to ensure that the position of the zero Gauss plane remains consistently located at the R-arc part of the crucible during the crystal ingot growth.

9. A crystal ingot growth apparatus for performing the crystal ingot growth method according to any one of claims 1 to 8, comprising:

a furnace body;
a crucible, located within the furnace body and containing a silicon melt;
a horizontal magnetic field generating structure arranged on a periphery of the furnace body and configured to output a horizontal magnetic field to the crucible;
a cusp magnetic field generating structure arranged on the periphery of the furnace body and configured to output a cusp magnetic field to the crucible; wherein the cusp magnetic field generating structure is located at a side of the horizontal magnetic field generating structure that is away from the top of the furnace body.

10. The crystal ingot growth apparatus according to claim 9, further comprising:
a first adjustment structure configured to control a movement of the horizontal magnetic field generating structure in an axial direction of the crystal ingot, enabling a distance between a maximum Gauss plane of the horizontal magnetic field and a liquid surface of the silicon melt to be less than a first preset value during the crystal ingot growth;

a second adjustment structure configured to control a movement of the cusp magnetic field generating structure in the axial direction of the crystal ingot, enabling a zero Gauss plane of the cusp magnetic field to be always at an R-arc part of the crucible during the crystal ingot growth.