

CRYSTAL GROWTH METHOD FOR FABRICATING LARGE-DIAMETER SILICON SINGLE CRYSTAL, SYSTEM, SILICON SINGLE CRYSTAL, AND MEDIUM

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims a priority of the Chinese patent application No. 202410827909.8 filed on June 25, 2024, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure relates to the field of semiconductor manufacturing, in particular to a crystal growth method for fabricating a large-diameter silicon single crystal, a system, a silicon single crystal, and a medium.

BACKGROUND

[0003] Recently, along with the development of semiconductor chips, for the chip fabricated using an advanced process, the tolerance for intrinsic defects in silicon wafers become increasingly stringent, and these intrinsic defects include Crystal Originated Pit (COP) caused by the clustering of vacancies and Large Dislocation Pit (LDP) caused by the clustering of interstitial atoms. These defects may lead to the deterioration of gate insulation performance and a leakage current in a back-end Fabrication Process (Fab).

[0004] Currently, a widely accepted method for controlling the intrinsic defects in crystal growth is the V/G theory, which is based on the Voronkov model. This model shows that the COP occurs in a case that a ratio V/G of a crystal pull speed V to a temperature gradient G at a solid-liquid interface is greater than a critical value ξ , the LDP occurs in a case that V/G is smaller than the critical value ξ , and a defect-free crystal is obtained only in a case that V/G is in the vicinity of a certain critical value ξ . However, the critical value ξ is not a constant value, so in the related art, usually the

distribution of defects in different hot zones and different process conditions need to be determined through a large quantity of experiments so as to obtain the defect-free crystals, thereby the cost for fabricating the defect-free crystals is relatively high.

SUMMARY

[0005] An object of the present disclosure is to provide a crystal growth method for fabricating a large-diameter silicon single crystal, a system, a silicon single crystal, and a medium, so as to rapidly determine a crystal growth parameter through simulated calculation, control a silicon melt to flow stably based on the crystal growth parameter to form the large-diameter silicon single crystal, and solve the problem in the related art where the cost for fabricating the defect-free crystals is relatively high.

[0006] In a first aspect, the present disclosure provides in some embodiments a crystal growth method for fabricating a large-diameter silicon single crystal, including: performing global two-dimensional simulation on a crystal growth process, and obtaining global temperature distribution, velocity field distribution and an initial solid-liquid interface value in the crystal growth process with a predetermined crystal growth device model and a predetermined crystal growth parameter; determining a boundary condition based on the global temperature distribution and the velocity field distribution, and performing local three-dimensional simulation on the crystal growth process based on the boundary condition to determine a target solid-liquid interface value; in the global two-dimensional simulation, adjusting the predetermined crystal growth parameter until the initial solid-liquid interface value is equal to the target solid-liquid interface value within a threshold range, and taking the adjusted predetermined crystal growth parameter as a reference crystal growth parameter; calculating a simulated defect in the crystal growth process based on the reference crystal growth parameter; iteratively optimizing the reference crystal growth parameter based on the simulated defect until the simulated defect meets a predetermined condition, and taking the optimized reference crystal growth parameter as a target crystal growth parameter; and fabricating a defect-free silicon single crystal based on the target crystal growth

parameter, the target crystal growth parameter including a hot zone parameter and a crystal growth process parameter.

[0007] In some embodiments of the present disclosure, the performing local three-dimensional simulation on the crystal growth process based on the boundary condition to determine a target solid-liquid interface value includes: determining a simulation scenario based on the boundary condition, and introducing a simulated magnetic field to the simulation scenario to perform three-dimensional simulation on the crystal growth process; and determining the target solid-liquid interface value based on the hot zone parameter, a physical property parameter of single crystal silicon, a turbulence model of a silicon melt, and a flow boundary layer, each of which is derived from the three-dimensional simulation.

[0008] In some embodiments of the present disclosure, in the adjusting the predetermined crystal growth parameter until the initial solid-liquid interface value is equal to the target solid-liquid interface value within a threshold range, the threshold range is smaller than or equal to 10%.

[0009] In some embodiments of the present disclosure, the calculating a simulated defect in the crystal growth process based on the reference crystal growth parameter includes: determining crystal growth parameter distribution in a crystal growth initial state; simulating defect distribution in the crystal growth initial state based on the crystal growth parameter distribution; and performing correction on the defect distribution based on a correction coefficient, and determining a defect cluster in the crystal growth initial state based on the corrected defect distribution.

[0010] In some embodiments of the present disclosure, the defect distribution includes a point defect concentration of interstitial atoms and a vacancy defect concentration. The performing correction on the defect distribution based on a correction coefficient includes: determining the correction coefficient based on historical data, and performing the correction on at least one of the point defect concentration of the interstitial atoms and the vacancy defect concentration based on the correction coefficient.

[0011] In some embodiments of the present disclosure, in a case that the point defect concentration of the interstitial atoms is corrected, the correction coefficient is greater than or equal to 1.0 and smaller than or equal to 1.3.

[0012] In some embodiments of the present disclosure, the predetermined crystal growth parameter includes a material viscosity value and thermal conductivity of a melt. The adjusting the predetermined crystal growth parameter until the initial solid-liquid interface value is equal to the target solid-liquid interface value within a threshold range includes: adjusting the material viscosity value and/or the thermal conductivity until the initial solid-liquid interface value is equal to the target solid-liquid interface value within the threshold range.

[0013] In some embodiments of the present disclosure, the iteratively optimizing the reference crystal growth parameter based on the simulated defect until the simulated defect meets a predetermined condition includes: in a case that the simulated defect meets COP, P-band ($V\text{-Cluster} > 25 \text{ nm}$), Pv ($V\text{-Cluster} = 12 \text{ nm} - 25 \text{ nm}$), Pi ($V\text{-Cluster} < 12 \text{ nm}$, and $I\text{-Cluster} < 0.5 \text{ nm}$), and LDP ($I\text{-Cluster} < 0.5 \text{ nm}$), taking the optimized reference crystal growth parameter as the target crystal growth parameter.

[0014] In a second aspect, the present disclosure provides in some embodiments a crystal growth system for fabricating a large-diameter silicon single crystal, including: a parameter obtaining module configured to perform global two-dimensional simulation on a crystal growth process, and obtain global temperature distribution, velocity field distribution and an initial solid-liquid interface value in the crystal growth process with a predetermined crystal growth device model and a predetermined crystal growth parameter; a first determination module configured to determine a boundary condition based on the global temperature distribution and the velocity field distribution, and perform local three-dimensional simulation on the crystal growth process based on the boundary condition to determine a target solid-liquid interface value; a first adjustment module configured to, in the global two-dimensional simulation, adjust the predetermined crystal growth parameter until the initial solid-liquid interface value is equal to the target solid-liquid interface value within a threshold range, and take the

adjusted predetermined crystal growth parameter as a reference crystal growth parameter; a second determination module configured to calculate a simulated defect in the crystal growth process based on the reference crystal growth parameter; a second adjustment module configured to iteratively optimize the reference crystal growth parameter based on the simulated defect until the simulated defect meets a predetermined condition, and take the optimized reference crystal growth parameter as a target crystal growth parameter; and a crystal fabrication module configured to fabricate a defect-free silicon single crystal based on the target crystal growth parameter, the target crystal growth parameter including a hot zone parameter and a crystal growth process parameter.

[0015] In a third aspect, the present disclosure provides in some embodiments a silicon single crystal fabricated using the above-mentioned crystal growth method. The quantity of defects with a vacancy defect size of 19 nm in any wafer obtained from the silicon single crystal is smaller than or equal to 25.

[0016] In a fourth aspect, the present disclosure provides in some embodiments an electronic device, including a processor and a memory. The processor is configured to execute an instruction stored in the memory to implement the above-mentioned crystal growth method.

[0017] In a fifth aspect, the present disclosure provides in some embodiments a computer storage medium storing therein at least one instruction. The at least one instruction is executed by a processor to implement the above-mentioned crystal growth method.

[0018] According to the crystal growth method for fabricating the large-diameter silicon single crystal, the system, the silicon single crystal and the medium provided in the embodiments of the present disclosure, on one hand, on the basis of two-dimensional simulation, the target solid-liquid interface value is determined through three-dimensional simulation, and then the predetermined crystal growth parameter is adjusted so that the solid-liquid interface value in the two-dimensional simulation is the same as the solid-liquid interface value in the three-dimensional simulation, so as to

improve the simulation precision in the crystal growth process. On the other hand, the boundary condition for the three-dimensional simulation is determined based on the global temperature distribution and the velocity speed distribution obtained in the two-dimensional simulation, so as to reduce a model size for the three-dimensional simulation, reduce simulation parameters, and improve the simulation efficiency. In addition, in the simulation, the crystal growth parameter is optimized based on the simulated defect so that the target crystal growth parameter obtained through simulation is directly used to fabricate a defect-free wafer, and a trial-and-error process is prevented through simulation, so it is able to significantly reduce experimental materials and a time cost, reduce an adjustment time during the fabrication, and improve the fabrication efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] Fig. 1 is a flow chart of a crystal growth method for fabricating a large-diameter silicon single crystal according to an embodiment of the present disclosure;

[0020] Fig. 2 is a schematic view showing temperature distribution for two-dimensional simulation according to an embodiment of the present disclosure;

[0021] Fig. 3 is a schematic view showing temperature distribution for three-dimensional simulation according to an embodiment of the present disclosure;

[0022] Fig. 4 is a flow chart of a method for determining a simulated defect according to an embodiment of the present disclosure;

[0023] Fig. 5 is a schematic view showing the comparison of defects related to a thermal stress and a correction coefficient according to an embodiment of the present disclosure;

[0024] Fig. 6 is another flow chart of the crystal growth method for fabricating the large-diameter silicon single crystal according to an embodiment of the present disclosure;

[0025] Fig. 7 is a schematic view showing the comparison between a defect simulation result and an experimental result of a crystal growth test at a variable growth speed according to an embodiment of the present disclosure;

[0026] Fig. 8 is a schematic view showing the comparison between a defect simulation result and an experimental result of a crystal growth test at a constant growth speed according to an embodiment of the present disclosure;

[0027] Fig. 9 is a schematic view showing a crystal growth system for fabricating a large-diameter silicon single crystal according to an embodiment of the present disclosure; and

[0028] Fig. 10 is a schematic view showing an electronic device according to an embodiment of the present disclosure.

[0029] The embodiments of the present disclosure have been shown through the above-mentioned drawings, and more detailed description will be given hereinafter. The drawings and the description are not used to limit the scope of the present disclosure in any way, but they are used to illustrate the present disclosure for a person skilled in the art with reference to specific embodiments.

DETAILED DESCRIPTION

[0030] The present disclosure will be described hereinafter in details in conjunction with illustrative embodiments, and examples thereof are shown in the drawings. Unless otherwise specified, identical numerals in different drawings represent identical or similar elements. The implementations in the following description do not include all implementations consistent with the embodiments of the present disclosure. In contrast, they are merely examples of devices and methods which are described in the appended claims and which are consistent with some aspects of the embodiments of the present disclosure.

[0031] During the fabrication of a semiconductor material, especially in a growth process of single crystal silicon, a crystal growth simulation technology plays a very important role. For the crystal growth simulation technology, a numerical

simulation method is used to predict and optimize a physical phenomenon in the crystal growth process, e.g., temperature distribution, a shape of a solid-liquid interface, a crystal stress and formation of defects.

[0032] In a conventional simulation technology, it is able to predict defect distribution in the crystal growth, and a crystal growth parameter is adjusted to reduce the defects and improve the crystal quality. Although a significant progress has been made in the conventional crystal growth simulation technology, there still exist the following challenges.

[0033] In a conventional two-dimensional simulation technology, basic parameters for the crystal growth, e.g., temperature distribution and a velocity field, are calculated rapidly, but the calculation is generally on the assumption that the crystal growth is axisymmetric, with a possible three-dimensional effect in an actual crystal growth process being omitted, e.g., a complex phenomenon caused by a thermal stress, a crystal stress and asymmetric flow. These factors may lead to the formation of the defects inside the crystal, e.g., COP and LDP, and the performance of a semiconductor element is significantly adversely affected by these defects.

[0034] In a conventional three-dimensional simulation technology, complexity in the crystal grow, including asymmetric flow and heat transfer, is captured more accurately. However, as compared with the two-dimensional simulation, the three-dimensional simulation needs to process more data and more complex boundary conditions, resulting in a significant increase in a computing time. In actual fabrication, it is crucial to rapidly obtain a simulation result for the real-time adjustment and optimization of process parameters.

[0035] In addition, the crystal growth process involves a plurality of interdependent process parameters, e.g., a pull speed, temperature control, a rotation speed, etc. There is a limitation for the conventional simulation technology in a case of optimizing these parameters, and it is difficult to take various related factors into consideration simultaneously, so it is difficult to find an optimal process condition for the fabrication of high-quality single crystal silicon.

[0036] Based on the above, the present disclosure provides in some embodiments a crystal growth method for fabricating a large-diameter silicon single crystal which, as shown in Fig. 1, includes Steps S110 to S160.

[0037] Step S110: performing global two-dimensional simulation on a crystal growth process, and obtaining global temperature distribution, velocity field distribution and an initial solid-liquid interface value in the crystal growth process with a predetermined crystal growth device model and a predetermined crystal growth parameter.

[0038] In some illustrative embodiments of the present disclosure, at first the global two-dimensional simulation is performed on the crystal growth process. To be specific, the two-dimensional simulation is performed on the crystal growth process on the predetermined crystal growth device model based on the predetermined crystal growth parameter, so as to obtain the global temperature distribution, the velocity speed distribution and the initial solid-liquid interface value in the crystal growth process.

[0039] The global temperature distribution includes temperature distribution for the crystal at each size in the crystal growth process, e.g., temperature distribution in a case that the crystal has a size of 100 mm, or temperature distribution in a case that the crystal has a size of 200 mm.

[0040] During the two-dimensional simulation on the crystal growth process, with reference to Fig. 2, a growth process of a crystal 21 in a furnace is simulated. The furnace includes a heat shield 22, a reflector, a crucible 24, a heater 25, an thermal insulation material 26, etc. A melt 23 is placed in the crucible 24.

[0041] The crucible has a double-layered structure consisting of a quartz crucible inside and a graphite crucible outside, it is a container for receiving the melt, and it is usually made of a high-temperature resistant material. The heater 25 surrounds the crucible and provides heat for the crystal growth. The thermal insulation material surrounds the heater to reduce a heat loss and maintain a stable temperature in the crucible. The reflector is arranged above the crucible, and functions as to block high-temperature radiant heat from the silicon melt in the crucible, the heater or a side wall

of the crucible during the crystal growth. In addition, as an assembly for prohibiting heat from being diffused into a low-temperature water-cooled body in the vicinity of a solid-liquid interface as a crystal growth interface, controlling the temperature gradient of a middle part of the crystal and a peripheral part of the crystal in an axial direction and the water-cooled body, dissipating the heat and protecting the crystal from being directly radiated in the furnace, temperature values of the reflector indicate temperature ranges in difference regions.

[0042] During the two-dimensional simulation process, the temperature distribution of each component is obtained as the global temperature distribution in the two-dimensional simulation. In a case of calculating the initial solid-liquid interface value based on the predetermined crystal growth parameter, a position of the solid-liquid interface is determined at first. The solid-liquid interface is a key region for the crystal growth, and a shape and stability thereof directly affect the crystal quality and the formation of the defect. Then, the initial solid-liquid interface value is calculated at the solid-liquid interface based on a physical model and a numerical simulation result. A specific calculation procedure of the initial solid-liquid interface value may refer to that in the related art, and thus will not be particularly defined herein.

[0043] Step S120: determining a boundary condition based on the global temperature distribution and the velocity field distribution, and performing local three-dimensional simulation on the crystal growth process based on the boundary condition to determine a target solid-liquid interface value.

[0044] In some illustrative embodiments of the present disclosure, the boundary condition for the three-dimensional simulation is determined based on the global temperature distribution and the velocity field distribution in a simulation result of the two-dimensional simulation process. To be specific, the boundary condition includes a temperature field, a velocity field, etc. The boundary condition is specifically determined in an output of the two-dimensional simulation, and it is used to determine a boundary for the three-dimensional simulation, i.e., constrain a model size in the

three-dimensional simulation process, so as to reduce an overall computing burden in the simulation process.

[0045] For example, as shown in Fig. 3, for the growth of a large-size silicon single crystal having a size of 300 mm, a horizontal magnetic field is used for the crystal growth, so three-dimensional, asymmetric flow occurs inside the melt. In order to simulate an actual growth condition of the silicon single crystal having a size of 300 mm in a more accurate manner, the three-dimensional simulation must be used. In a case of obtaining a model for the three-dimensional simulation, part of regions in a model for the two-dimensional simulation are obtained based on the boundary condition as the model for the three-dimensional simulation.

[0046] In some illustrative embodiments of the present disclosure, after determining the boundary condition for the three-dimensional simulation, desired horizontal magnetic field and cusp magnetic field are added, and the target solid-liquid interface value in the three-dimensional simulation process is calculated based on a hot zone parameter, a physical property parameter of single crystal silicon, a turbulence model of a silicon melt, and a flow boundary layer, each of which is derived from the three-dimensional simulation. To be specific, the hot zone parameter, the physical property parameter of single crystal silicon, the turbulence model of the silicon melt and the flow boundary layer are inputted into computing software to calculate the target solid-liquid interface value. A specific type of the computing software may refer to that in the related art, and thus will not be particularly defined herein.

[0047] The hot zone parameter refers to a series of parameters that affect heat distribution and heat transfer in the crystal growth process. These parameters may include a temperature of the heater, a heat flux density, a cooling rate, thermal conductivity of a thermal insulation material, a geometric structure of the furnace, etc. The physical property parameter of single crystal silicon refers to parameters for describing physical and chemical characteristics of single crystal silicon, e.g., thermal conductivity, specific heat capacity, density, melting point, crystal structure, doping concentration, etc. The turbulence model refers to a mathematical model for describing

and predicting turbulent flow, with such factors as viscosity of a fluid, velocity distribution and a temperature gradient being taken into consideration. The flow boundary layer refers to a fluid layer in the vicinity of a surface of a solid, and the velocity of the fluid gradually increases from zero (on the surface of the solid) to free-flow velocity. During the crystal growth, a behavior of the flow boundary layer may affect the heat transfer, mass transport and defect delivery. Through optimizing characteristics of the flow boundary layer, e.g., thickness and velocity distribution, it is able to help to control the crystal growth quality and speed.

[0048] Step S130: in the global two-dimensional simulation, adjusting the predetermined crystal growth parameter until the initial solid-liquid interface value is equal to the target solid-liquid interface value within a threshold range, and taking the adjusted predetermined crystal growth parameter as a reference crystal growth parameter.

[0049] In some illustrative embodiments of the present disclosure, after determining the target solid-liquid interface value, the predetermined crystal growth parameter is adjusted based on the target solid-liquid interface value to perform parameter fitting on the three-dimensional simulation process so that the initial solid-liquid interface value is equal to the target solid-liquid interface value within the threshold range, and then the adjusted predetermined crystal growth parameter is taken as the reference crystal growth parameter. To be specific, a material viscosity value and/or thermal conductivity of a melt in the crystal growth parameters are adjusted, so as to perform the parameter fitting on the three-dimensional simulation process.

[0050] The threshold range is used to represent an allowable error range, and it may be an error range of 10%, or a specific numerical value, e.g., 1 mm to 2 mm. Of course, a specific numerical value may be defined according to the practical needs, which will not be particularly defined herein.

[0051] Step S140: calculating a simulated defect in the crystal growth process based on the reference crystal growth parameter.

[0052] In some illustrative embodiments of the present disclosure, after obtaining the above-mentioned reference crystal growth parameter, the simulated defect in the crystal growth process is simulated based on the reference crystal growth parameter. To be specific, initial steady state calculation and defect cluster calculation are performed based on the above-mentioned reference crystal growth parameter in the two-dimensional simulation, so as to simulate the simulated defect in the crystal growth process.

[0053] Step S150: iteratively optimizing the reference crystal growth parameter based on the simulated defect until the simulated defect meets a predetermined condition, and taking the optimized reference crystal growth parameter as a target crystal growth parameter.

[0054] In an illustrative embodiment of the present disclosure, after obtaining the simulated defect, the reference crystal growth parameter is adjusted based on the simulated defect, then the simulated defect is calculated and the reference crystal growth parameter is adjusted again, until the simulated defect meets the predetermined condition. The predetermined condition includes that fewest simulated defects are obtained, i.e., an optimal reference crystal growth parameter is obtained. In addition, the predetermined condition includes that the quantity of simulated defects meets the process requirement, and the process requirement is set according to the practical need, which will not be particularly defined herein.

[0055] It should be appreciated that, during the adjustment of the reference crystal growth parameters, part of, or all of, the reference crystal growth parameters are adjusted based on crystal growth experience and a V/G theory. The specific parameters to be adjusted may further be set according to the practical need, which will not be particularly defined herein.

[0056] Step S160: fabricating a defect-free silicon single crystal based on the target crystal growth parameter, the target crystal growth parameter including a hot zone parameter and a crystal growth process parameter.

[0057] After obtaining the target crystal growth parameter, the defect-free silicon single crystal is obtained based on the target crystal growth parameter. The target crystal growth parameter includes the hot zone parameter and the crystal growth process parameter. The crystal growth process parameter includes a growth speed, temperature control, a rotation speed, a gas environment, a crucible position, types, concentrations and introducing times of dopants, a diameter of the crystal, a cooling rate, etc., in the crystal growth process. More or fewer crystal growth process parameters may further be set according to the process requirement, which will not be particularly defined herein.

[0058] According to the crystal growth method for fabricating the large-diameter silicon single crystal provided in the embodiments of the present disclosure, on one hand, on the basis of two-dimensional simulation, the target solid-liquid interface value is determined through three-dimensional simulation, and then the predetermined crystal growth parameter is adjusted so that the solid-liquid interface value in the two-dimensional simulation is the same as the solid-liquid interface value in the three-dimensional simulation, so as to improve the simulation precision in the crystal growth process. On the other hand, the boundary condition for the three-dimensional simulation is determined based on the global temperature distribution and the velocity speed distribution obtained in the two-dimensional simulation, so as to reduce a model size for the three-dimensional simulation, reduce simulation parameters, and improve the simulation efficiency. In addition, in the simulation, the crystal growth parameter is optimized based on the simulated defect so that the target crystal growth parameter obtained through simulation is directly used to fabricate a defect-free wafer, and a trial-and-error process is prevented through simulation, so it is able to significantly reduce experimental materials and a time cost, reduce an adjustment time during the fabrication, and improve the fabrication efficiency.

[0059] In some illustrative embodiments of the present disclosure, the predetermined crystal growth parameter includes the material viscosity value of the

melt, the thermal conductivity of the melt, a hot zone condition in the simulation process, and the crystal growth process parameter.

[0060] In a process of adjusting the predetermined crystal growth parameter until the initial solid-liquid interface value is equal to the target solid-liquid interface value within the threshold range and taking the adjusted predetermined crystal growth parameter as the reference crystal growth parameter, parameters that affect the solid-liquid interface value may be adjusted. The parameters that affect the solid-liquid interface value may be obtained as a matter of experience or experiments, and a specific obtaining procedure will not be particularly defined herein. For example, one or two of the material viscosity and the thermal conductivity is adjusted, so that the initial solid-liquid interface value is equal to the target solid-liquid interface value within the threshold range.

[0061] For example, the material viscosity value is adjusted at different crystal lengths in the growth process, so that the initial solid-liquid interface value is equal to the target solid-liquid interface value within the threshold range. For example, Table 1 shows material viscosity values of the melt set for different crystal lengths in a case that the initial solid-liquid interface value is equal to the target solid-liquid interface value within the threshold range.

Table 1

Crystal length (mm)	100	150	200	350	500	700	900	1100	1300	1500	1700	1800	1900
Material viscosity value (Pa-s)	0.04	0.07	0.1	0.12	0.15	0.18	0.2	0.22	0.25	0.3	0.35	0.4	0.0004

[0062] As shown in Table 1, in a case of different crystal lengths, in order to enable the initial solid-liquid interface value to be equal to the target solid-liquid

interface value, different material viscosity values or a same material viscosity value of the melt need to be set, i.e., different viscosity values of the melt need to be set based on a current length of the crystal.

[0063] In some illustrative embodiments of the present disclosure, with reference to Fig. 4, the determining the simulated defect in the crystal growth process based on the reference crystal growth parameter includes Steps S410 to S440.

[0064] Step S410: determining crystal growth parameter distribution in a crystal growth initial state.

[0065] In some illustrative embodiments of the present disclosure, the crystal growth initial state is a state in a case that the crystal length is 100 mm or 200 mm. A specific crystal length in the crystal growth initial state may be set according to the practical need, which will not be particularly defined herein.

[0066] The crystal growth parameter distribution includes temperature distribution, velocity distribution and crystal stress distribution in the furnace in the crystal growth initial state.

[0067] To be specific, initial steady state calculation is performed using crystal simulation software for the crystal growth initial state. It should be appreciated that, during the calculation, the thermal stress distribution may be calculated simultaneously, so as to prevent the thermal stress from affecting the defect, thereby to further improve the accuracy of the obtained target crystal growth parameter.

[0068] For example, with reference to Fig. 5, “without stress” represents that an influence of the thermal stress on a point defect concentration is not taken into consideration in the simulation process, and “with stress” represents that the influence of the thermal stress is taken into consideration in the simulation process, i.e., the distribution and concentration of point defects are changed due to the thermal stress.

[0069] “Top” and “tail” represent two different regions in the crystal growth process, specifically two ends of the crystal. A radius $R_v[\text{nm}]$ of an interstitial void represents a volume or size of an interstitial site of a lattice, in unit of nm. As shown in Fig. 5, the distribution and concentration of the point defects are changed due

to the thermal stress. Hence, in the embodiments of the present disclosure, in a case of determining the parameter distribution, the thermal stress distribution is calculated, so as to increase the accuracy of the obtained target crystal growth parameter, thereby to enable the target crystal growth parameter to approach to actual experimental data in a better manner.

[0070] Step S420: simulating defect distribution in the crystal growth initial state based on the crystal growth parameter distribution.

[0071] In some illustrative embodiments of the present disclosure, the defect distribution includes a point defect concentration of interstitial atoms and a vacancy defect concentration. After obtaining the parameter distribution, the point defect distribution in the crystal in the initial steady state is calculated based on the parameter distribution. A specific calculation method may refer to that in the related art, and thus will not be particularly defined herein.

[0072] Step S430: performing correction on the defect distribution based on a correction coefficient, and determining a defect cluster in the crystal growth initial state based on the corrected defect distribution.

[0073] In some illustrative embodiments of the present disclosure, the correction coefficient is obtained based on historical data. To be specific, the correction coefficient is determined based on historical defect distribution and actual defect distribution in historical experiments, and then the defect distribution is corrected based on the correction coefficient.

[0074] The correction coefficient includes a correction coefficient for the point defect concentration of the interstitial atoms and a correction coefficient for the vacancy defect concentration. A specific value of the correction coefficient may be obtained based on a large amount of historical data, which will not be particularly defined herein.

[0075] In some illustrative embodiments of the present disclosure, it is presumed that the correction coefficient includes a correction coefficient for a point defect concentration C_i of the interstitial atoms, and it has a value greater than or equal to 1.0 and smaller than or equal to 1.3. In some embodiments of the present disclosure, the

correction coefficient is 1.1, the point defect connection C_i is multiplied by 1.1 to obtain a defect distribution result which is consistent with that in the experiment. The point defect concentration of the interstitial atoms is corrected based on the correction coefficient, so as to obtain the more accurate defect distribution, thereby to obtain the more precise target crystal growth parameter.

[0076] With reference to Fig. 5, an adjusted point defect concentration C_i adjusted of the interstitial atoms represents that the point defect concentration of the interstitial atoms is adjusted after comparing a simulation result with experimental data, so as to reflect the physical phenomenon in the actual crystal growth process in a more accurate manner.

[0077] After correcting the defect distribution, the defect cluster in the crystal growth initial state is calculated based on the corrected defect distribution. To be specific, a defect cluster calculation function in the crystal simulation software is used to simulate how the point defects are clustered to form a larger defect cluster. A specific calculation procedure may refer to that in the related art, and thus will not be particularly defined herein.

[0078] Step S440: determining the simulated defect in the crystal growth process based on the defect cluster in the crystal growth initial state and the reference crystal growth parameter.

[0079] In some illustrative embodiments of the present disclosure, after determining the defect cluster in the crystal growth initial state, the simulated defect in the crystal growth process is determined based on the defect cluster in the crystal growth initial state and the reference crystal growth parameter.

[0080] To be specific, the defect cluster in the crystal growth initial state and the reference crystal growth parameter are used as input parameters to obtain the simulated defect in the crystal growth process through the crystal simulation software CGSim.

[0081] After obtaining the simulated defect in the crystal growth process, the reference crystal growth parameter is adjusted based on the simulated defect, until the simulated defect meets a predetermined condition.

[0082] In some illustrative embodiments of the present disclosure, the predetermined condition includes COP ($V\text{-Cluster} > 25 \text{ nm}$), Pv ($V\text{-Cluster} = 12 \text{ nm} - 25 \text{ nm}$), Pi ($V\text{-Cluster} < 12 \text{ nm}$, and $I\text{-Cluster} < 0.5 \text{ nm}$), and LDP ($I\text{-Cluster} < 0.5 \text{ nm}$).

[0083] COP represents a vacancy cluster, Pv represents a vacancy-dominant defect-free region, Pi represents an interstitial atom-dominant defect-free region, LDP represents a large dislocation pit caused by the interstitial atoms, I-Cluster represents an interstitial cluster size, V-Cluster represents a vacancy defect size.

[0084] It should be appreciated that, the above predetermined condition is for illustrative purposes only, and a specific form of the predetermined condition may be set according to the process requirement, which will not be particularly defined herein.

[0085] The hot zone parameter and/or the crystal growth process parameter in the reference crystal growth parameter are adjusted, and in a case that the simulated defect meets the predetermined condition, the adjusted reference crystal growth parameter is outputted as the target crystal growth parameter and serves a crystal growth parameter for fabricating a crystal ingot. For example, the target crystal growth parameter includes that a Maximum Gaussian Plane Position (MGP) is greater than or equal to -200 mm and smaller than or equal to 150 mm , Magnetic Intensity (MI) is greater than or equal to 2500 G and smaller than or equal to 3800 G , Crystal Rotation (S/R) is greater than or equal to 8 rpm and smaller than or equal to 12 rpm , a crucible rotation speed is greater than or equal to -0.2 rpm and smaller than or equal to 2.5 rpm , an Argon Gas Flow Rate (ArGFR) is greater than or equal to 60 slm and smaller than or equal to 220 slm , and a Furnace Pressure (FP) is greater than or equal to 20 Tor and smaller than or equal to 100 Tor .

[0086] It should be appreciated that, the types and values of the target crystal growth parameters are for illustrative purposes only, and they may be set according to practical need, which will not be particularly defined herein.

[0087] The crystal growth method for fabricating the large-diameter silicon single crystal will be described hereinafter with reference to Fig. 6. The method includes the following steps.

[0088] Step S610: performing global two-dimensional simulation on a crystal growth process, and obtaining global temperature distribution, velocity field distribution and an initial solid-liquid interface value in the crystal growth process with a predetermined crystal growth device model and a predetermined crystal growth parameter.

[0089] Step S620: determining a boundary condition based on the global temperature distribution and the velocity field distribution, and performing local three-dimensional simulation on the crystal growth process based on the boundary condition to determine a target solid-liquid interface value.

[0090] Step S630: adjusting a viscosity value and/or thermal conductivity of a melt.

[0091] Step S640: determining whether the initial solid-liquid interface value is equal to the target solid-liquid interface value, if not, proceeding to Step S630, and if yes, proceeding to Step S650 to determine parameter distribution in a crystal growth initial state.

[0092] Step S660: determining defect distribution in the crystal growth initial state based on the parameter distribution.

[0093] Step S670: performing correction on the defect distribution based on a correction coefficient, and determining a defect cluster in the crystal growth initial state based on the corrected defect distribution.

[0094] Step S680: determining a simulated defect in the crystal growth process based on the defect cluster in the crystal growth initial state and the reference crystal growth parameter.

[0095] Step S690: adjusting a hot zone parameter and a crystal growth processing parameter based on the simulated defect.

[0096] Step S611: determining whether the simulated defect meets a predetermined condition, if not, proceeding to Step S690, and if yes, proceeding to Step S612 to output a target crystal growth parameter.

[0097] It should be appreciated that, specific details of Steps S610 to S612 have been described hereinabove, and thus will not be particularly defined herein.

[0098] In some illustrative embodiments of the present disclosure, Fig. 7 is a schematic view showing the comparison between a defect simulation result and an experimental result of a crystal growth test at a variable growth speed. With reference to Fig. 7, the axial defect simulation result of the crystal is consistent with the experimental result, and an error between a growth speed at the defect-free region in the simulation result and an actual growth speed is smaller than 1%.

[0099] Fig. 8 is a schematic view showing the comparison between a defect simulation result and an experimental result of a crystal growth test at a constant growth speed. With reference to Fig. 8, the radial defect simulation result of the crystal is consistent with the experimental result, and an identity between the radial defect simulation result and the experimental result is greater than 90%. As shown in Fig. 8, an identity between a simulation result of a 19 nm Local Laser Scatter (LLS) defect and the experimental result is also relatively high.

[00100] As shown in Figs. 7 and 8, the identity between the simulation result obtained through the crystal growth method provided in the embodiments of the present disclosure and the experimental result is high, so the accuracy of the obtained target crystal growth parameter is high.

[00101] In a word, according to the crystal growth method for fabricating the large-diameter silicon single crystal in the embodiments of the present disclosure, on one hand, on the basis of two-dimensional simulation, the target solid-liquid interface value is determined through three-dimensional simulation, and then the predetermined crystal growth parameter is adjusted so that the solid-liquid interface value in the two-dimensional simulation is the same as the solid-liquid interface value in the three-dimensional simulation, so as to improve the simulation precision in the crystal growth process. On the other hand, the boundary condition for the three-dimensional simulation is determined based on the global temperature distribution and the velocity speed distribution obtained in the two-dimensional simulation, so as to reduce a model size

for the three-dimensional simulation, reduce simulation parameters, and improve the simulation efficiency. In addition, in the simulation, the crystal growth parameter is optimized based on the simulated defect so that the target crystal growth parameter obtained through simulation is directly used to fabricate a defect-free wafer, and a trial-and-error process is prevented through simulation, so it is able to significantly reduce experimental materials and a time cost, reduce an adjustment time during the fabrication, and improve the fabrication efficiency. Further, the defect distribution is adjusted based on the correction coefficient, so it is able to increase the accuracy of target crystal growth parameter obtained based on the simulated defect, and improve the quality of the crystal ingot generated based on the target crystal growth parameter.

[00102] The present disclosure further provides in some embodiments a crystal ingot fabricated using the above-mentioned crystal growth method based on the target crystal growth parameter. The quantity of defects with a vacancy defect size of 19 nm in any wafer obtained from the crystal ingot is smaller than or equal to 25. The crystal growth method has been described hereinabove, and thus will not be particularly defined herein.

[00103] It should be appreciated that, a specific value of the vacancy defect size and the quantity of defects in any wafer obtained from the crystal ingot may also be set according to the practical need. For example, the quantity of defects with a vacancy defect size of 20 nm in the wafer is smaller than or equal to 24, or the quantity of defects with a vacancy defect size of 35 nm in the wafer is smaller than or equal to 12, which will not be particularly defined herein.

[00104] The present disclosure further provides in some embodiments a crystal growth system 900 for fabricating a large-diameter silicon single crystal which, as shown in Fig. 9, includes a parameter obtaining module 910, a first determination module 920, a first adjustment module 930, a second determination module 940, a second adjustment module 950, and a crystal fabrication module 960.

[00105] The parameter obtaining module 910 is configured to perform global two-dimensional simulation on a crystal growth process, and obtain global temperature

distribution, velocity field distribution and an initial solid-liquid interface value in the crystal growth process with a predetermined crystal growth device model and a predetermined crystal growth parameter.

[00106] The first determination module 920 is configured to determine a boundary condition based on the global temperature distribution and the velocity field distribution, and perform local three-dimensional simulation on the crystal growth process based on the boundary condition to determine a target solid-liquid interface value.

[00107] The first adjustment module 930 is configured to, in the global two-dimensional simulation, adjust the predetermined crystal growth parameter until the initial solid-liquid interface value is equal to the target solid-liquid interface value within a threshold range, and take the adjusted predetermined crystal growth parameter as a reference crystal growth parameter.

[00108] The second determination module 940 is configured to iteratively optimize the reference crystal growth parameter based on the simulated defect until the simulated defect meets a predetermined condition, and take the optimized reference crystal growth parameter as a target crystal growth parameter.

[00109] The second adjustment module 950 is configured to iteratively optimize the reference crystal growth parameter based on the simulated defect until the simulated defect meets a predetermined condition, and take the optimized reference crystal growth parameter as a target crystal growth parameter.

[00110] The crystal fabrication module 960 is configured to fabricate a defect-free silicon single crystal based on the target crystal growth parameter, the target crystal growth parameter including a hot zone parameter and a crystal growth process parameter.

[00111] In some illustrative embodiments of the present disclosure, the first determination module 920 is further configured to determine a simulation scenario based on the boundary condition, and add a simulated magnetic field to the simulation scenario to perform three-dimensional simulation on the crystal growth process; and

determine the target solid-liquid interface value based on the hot zone parameter, a physical property parameter of single crystal silicon, a turbulence model of a silicon melt, and a flow boundary layer, each of which is derived from the three-dimensional simulation.

[00112] In some illustrative embodiments of the present disclosure, the threshold voltage is smaller than or equal to 10%.

[00113] In some illustrative embodiments of the present disclosure, the first adjustment module 930 is further configured to: determine parameter distribution in a crystal growth initial state; determine defect distribution in the crystal growth initial state based on the parameter distribution; perform correction on the defect distribution based on a correction coefficient, and determine a defect cluster in the crystal growth initial state based on the corrected defect distribution; and determine a simulated defect in the crystal growth process based on the defect cluster in the crystal growth initial state and the reference crystal growth parameter. The parameter distribution includes temperature distribution in a furnace, velocity distribute, and stress distribution in the crystal in the crystal growth initial state.

[00114] In some illustrative embodiments of the present disclosure, the first adjustment module 930 is further configured to determine the correction coefficient based on historical data, and perform the correction on at least one of a point defect concentration of the interstitial atoms and a vacancy defect concentration based on the correction coefficient.

[00115] In some illustrative embodiments of the present disclosure, in a case that the point defect concentration of the interstitial atoms is corrected, the correction coefficient is greater than or equal to 1.0 and smaller than or equal to 1.3.

[00116] In some illustrative embodiments of the present disclosure, the predetermined crystal growth parameter includes a material viscosity value and thermal conductivity of a melt. The first adjustment module 930 is further configured to adjust the material viscosity value and/or the thermal conductivity until the initial solid-liquid

interface value is equal to the target solid-liquid interface value within the threshold range.

[00117] In some illustrative embodiments of the present disclosure, the second determination module 940 is further configured to adjust the hot zone parameter and/or the crystal growth process parameter, until the simulated defect meets a predetermined condition.

[00118] In some illustrative embodiments of the present disclosure, the iteratively optimizing the reference crystal growth parameter based on the simulated defect until the simulated defect meets the predetermined condition includes, in a case that the simulated defect meets COP, P-band ($V\text{-Cluster} > 25 \text{ nm}$), Pv ($V\text{-Cluster} = 12 \text{ nm} - 25 \text{ nm}$), Pi ($V\text{-Cluster} < 12 \text{ nm}$, and $I\text{-Cluster} < 0.5 \text{ nm}$), and LDP ($I\text{-Cluster} < 0.5 \text{ nm}$), taking the optimized reference crystal growth parameter as the target crystal growth parameter.

[00119] Fig. 10 is a block diagram of an electronic device according to an embodiment of the present disclosure. In some illustrative embodiments of the present disclosure, the electronic device includes at least one of a smart phone, a smart watch, a desktop computer, a notebook, a virtual reality terminal, an augmented reality terminal, a wireless terminal, and a laptop computer. The electronic device has a communication function, and it may access a wired network or a wireless network. The electronic device generally refers to one of a plurality of terminals, and more or fewer terminals may be provided. It should be appreciated that, the electronic device is used to perform calculation and processing in the technical solution of the present disclosure, which will not be particularly defined herein.

[00120] It should be appreciated that, the above-mentioned device is for illustrative purposes only, and it may be implemented in any other way. For example, the units/modules are provided merely on the basis of their logic functions, and in actual use, they may be provided in any other way. For example, the units, modules or assemblies may be combined, or integrated into another system, or some features may be omitted or not executed.

[00121] In addition, unless otherwise specified, the functional units/modules in the embodiments of the present disclosure may be integrated into one unit/module, or the functional units/modules may exist independently, or two or more functional units/modules may be combined together. The integrated functional units/modules may be implemented in a hardware form or in the form of a software program module.

[00122] In a case that the integrated units/modules are implemented in a hardware form, the hardware may be a digital circuit or an analog circuit. Physical implementation of the hardware structure includes, but not limited to, transistor and memristor. Unless otherwise specified, a processor may be any appropriate hardware processor, e.g., Central Processing Unit (CPU), Graphics Processing Unit (GPU), Field-Programmable Gate Array (FPGA), Digital Signal Processor (DSP), and Application Specific Integrated Circuit (ASIC). Unless otherwise specified, a storage unit may be any appropriate magnetic storage medium or magneto-optical storage medium, e.g., Resistive Random Access Memory (RRAM), Dynamic Random Access Memory (DRAM), Static Random-Access Memory (SRAM), Enhanced Dynamic Random Access Memory (EDRAM), High-Bandwidth Memory (HBM), or Hybrid Memory Cube (HMC).

[00123] In a case that the integrated functional units/modules are implemented in a software form and sold or used as a separate product, they may be stored in a computer-readable medium. Based on this, the technical solutions of the present disclosure, partial or full, or parts of the technical solutions of the present disclosure contributing to the related art, may appear in the form of software products, which may be stored in a memory and includes several instructions so as to enable a computer device (a personal computer, a server or a network device) to execute all or parts of the steps of the methods according to the embodiments of the present disclosure. The memory includes any medium storing therein a program code, e.g., a universal serial bus (USB) flash disk, a Read-Only Memory (ROM), a Random Access Memory (RAM), a mobile hard disk, a magnetic disk or an optical disk.

[00124] As shown in Fig. 10, the electronic device 1000 includes at least one processor 1010, a memory 1020 and a communication interface 1030.

[00125] The memory 1020 is configured to store therein a program. To be specific, the program includes a program code, and the program code includes a computer operating instruction.

[00126] The memory 1020 includes a high-speed RAM, or a non-volatile memory, e.g., at least one magnetic disk memory.

[00127] The processor 1010 is configured to execute a computer-executable instruction stored in the memory 1020, so as to implement the above-mentioned crystal growth method. The processor 1010 may be a CPU, an ASIC, or one or more ICs configured to implement the embodiments of the present disclosure.

[00128] The electronic device 1000 further includes a communication interface 1030 to implement communication and interaction with an external device. During the implementation, in a case that the communication interface 1030, the memory 1020 and the processor 1010 are implemented independently, they may be coupled to each other and communicate with each other via a bus. The bus may be an Industry Standard Architecture (ISA) bus, a Peripheral Component Interconnect (PCI) bus or an Extended Industry Standard Architecture (EISA) bus. The bus includes address bus, data bus and control bus, but it does not mean that there is merely one bus or one type of buses.

[00129] Optionally, during the implementation, in a case that the communication interface 1030, the memory 1020 and the processor 1010 are integrated into one chip, they communicate with each other via an internal interface.

[00130] The present disclosure further provides in some embodiments a computer-readable storage medium, which includes any medium storing therein a program code, e.g., a USB flash disk, a mobile hard disk, a ROM, a RAM, a magnetic disk or an optical disk. To be specific, the computer-readable storage medium stores therein a program instruction, and the program instruction is executed by to implement the above-mentioned crystal growth method.

[00131] The present disclosure further provides in some embodiments a computer program product. The computer program product includes a computer instruction stored in a computer-readable storage medium. A processor of an electronic device reads the computer instruction from the computer-readable storage medium to implement the above-mentioned crystal growth method.

[00132] It should be appreciated that, in one or more embodiments of the present disclosure, the functions may be implemented via hardware, software, firmware, or a combination thereof. In a case that the functions are implemented through software, these functions may be stored in the computer-readable medium or transmitted as one or more instructions or codes on the computer-readable medium. The computer-readable medium may include a computer-readable storage medium and a communication medium. The communication medium may include any medium capable of transmitting a computer program from one place to another place. The storage medium may include any available medium capable of being accessed by a general-purpose or dedicated computer.

[00133] Each of the above embodiments merely focuses on the difference from the others, and the parts not described in details in one embodiment may refer to the relevant description in the other embodiments. The technical features in the embodiments may be combined in any way, and for ease of description, not all possible combinations of the technical features are described. However, these combinations shall also fall within the scope of the specification in a case of no conflict.

[00134] Other embodiments of the present disclosure will be apparent to those skilled in the art from consideration of the specification and practice of the present disclosure disclosed here. This application is intended to cover any variations, uses, or adaptations of the disclosure following the general principles thereof and including such departures from the disclosure as come within known or customary practice in the art.

[00135] It should be appreciated that, the present disclosure is not limited to the exact construction that has been described hereinabove and illustrated in the

accompanying drawings, and that various modifications and changes can be made without departing from the scope thereof. It is intended that the scope of the present disclosure is only limited by the appended claims.

What is claimed is:

1. A crystal growth method for fabricating a large-diameter silicon single crystal, comprising:

performing global two-dimensional simulation on a crystal growth process, and obtaining global temperature distribution, velocity field distribution and an initial solid-liquid interface value in the crystal growth process with a predetermined crystal growth device model and a predetermined crystal growth parameter;

determining a boundary condition based on the global temperature distribution and the velocity field distribution, and performing local three-dimensional simulation on the crystal growth process based on the boundary condition to determine a target solid-liquid interface value;

in the global two-dimensional simulation, adjusting the predetermined crystal growth parameter until the initial solid-liquid interface value is equal to the target solid-liquid interface value within a threshold range, and taking the adjusted predetermined crystal growth parameter as a reference crystal growth parameter;

calculating a simulated defect in the crystal growth process based on the reference crystal growth parameter;

iteratively optimizing the reference crystal growth parameter based on the simulated defect until the simulated defect meets a predetermined condition, and taking the optimized reference crystal growth parameter as a target crystal growth parameter; and

fabricating a defect-free silicon single crystal based on the target crystal growth parameter, the target crystal growth parameter comprising a hot zone parameter and a crystal growth process parameter.

2. The crystal growth method according to claim 1, wherein the performing local three-dimensional simulation on the crystal growth process based on the boundary condition to determine a target solid-liquid interface value comprises:

determining a simulation scenario based on the boundary condition, and introducing a simulated magnetic field to the simulation scenario to perform three-dimensional simulation of the crystal growth process; and

determining the target solid-liquid interface value based on the hot zone parameter, a physical property parameter of single crystal silicon, a turbulence model of a silicon melt, and a flow boundary layer, each of which is derived from the three-dimensional simulation.

3. The crystal growth method according to claim 1, wherein in the adjusting the predetermined crystal growth parameter until the initial solid-liquid interface value is equal to the target solid-liquid interface value within a threshold range, the threshold range is smaller than or equal to 10%.

4. The crystal growth method according to claim 1, wherein the calculating a simulated defect in the crystal growth process based on the reference crystal growth parameter comprises:

determining crystal growth parameter distribution in a crystal growth initial state;

simulating defect distribution in the crystal growth initial state based on the crystal growth parameter distribution;

performing correction on the defect distribution based on a correction coefficient, and determining a defect cluster in the crystal growth initial state based on the corrected defect distribution; and

determining the simulated defect in the crystal growth process based on the defect cluster in the crystal growth initial state and the reference crystal growth parameter.

5. The crystal growth method according to claim 4, wherein the defect distribution comprises a point defect concentration of interstitial atoms and a vacancy defect concentration;

wherein the performing correction on the defect distribution based on a correction coefficient comprises:

determining the correction coefficient based on historical data, and performing the correction on at least one of the point defect concentration of interstitial atoms and the vacancy defect concentration based on the correction coefficient.

6. The crystal growth method according to claim 5, wherein in a case that the point defect concentration of the interstitial atoms is corrected, the correction coefficient is greater than or equal to 1.0 and smaller than or equal to 1.3.

7. The crystal growth method according to claim 1, wherein the predetermined crystal growth parameter comprises a material viscosity value and thermal conductivity of a melt,

wherein the adjusting the predetermined crystal growth parameter until the initial solid-liquid interface value is equal to the target solid-liquid interface value within a threshold range comprises:

adjusting the material viscosity value and/or the thermal conductivity until the initial solid-liquid interface value is equal to the target solid-liquid interface value within the threshold range.

8. The crystal growth method according to claim 1, wherein the iteratively optimizing the reference crystal growth parameter based on the simulated defect until the simulated defect meets a predetermined condition comprises:

in a case that the simulated defect meets Crystal Originated Pit (COP), P-band (V-Cluster > 25 nm), Pv (V-Cluster=12 nm-25 nm), Pi (V-Cluster < 12 nm, and I-

Cluster ≤ 0.5 nm), and Large Dislocation Pit (LDP) (I-Cluster ≤ 0.5 nm), taking the optimized reference crystal growth parameter as the target crystal growth parameter.

9. A crystal growth system for fabricating a large-diameter silicon single crystal, comprising:

a parameter obtaining module configured to perform global two-dimensional simulation on a crystal growth process, and obtain global temperature distribution, velocity field distribution and an initial solid-liquid interface value in the crystal growth process with a predetermined crystal growth device model and a predetermined crystal growth parameter;

a first determination module configured to determine a boundary condition based on the global temperature distribution and the velocity field distribution, and perform local three-dimensional simulation on the crystal growth process based on the boundary condition to determine a target solid-liquid interface value;

a first adjustment module configured to, in the global two-dimensional simulation, adjust the predetermined crystal growth parameter until the initial solid-liquid interface value is equal to the target solid-liquid interface value within a threshold range, and take the adjusted predetermined crystal growth parameter as a reference crystal growth parameter;

a second determination module configured to calculate a simulated defect in the crystal growth process based on the reference crystal growth parameter;

a second adjustment module configured to iteratively optimize the reference crystal growth parameter based on the simulated defect until the simulated defect meets a predetermined condition, and take the optimized reference crystal growth parameter as a target crystal growth parameter; and

a crystal fabrication module configured to fabricate a defect-free silicon single crystal based on the target crystal growth parameter, the target crystal growth parameter comprising a hot zone parameter and a crystal growth process parameter.

10. A silicon single crystal fabricated using the crystal growth method according to any one of claims 1 to 8,

wherein the quantity of defects with a vacancy defect size of 19 nm in any wafer obtained from the silicon single crystal is smaller than or equal to 25.

11. An electronic device, comprising a processor and a memory, wherein the processor is configured to execute an instruction stored in the memory to implement the crystal growth method according to any one of claims 1 to 8.

12. A computer storage medium storing therein at least one instruction, wherein the at least one instruction is executed by a processor to implement the crystal growth method according to any one of claims 1 to 8.