

EPITAXIAL GROWTH METHOD AND EPITAXIAL WAFER

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present disclosure claims the priority to the Chinese patent application No. 202411494740.5 filed in China on October 24, 2024, a disclosure of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure relates to the field of semiconductor processing and manufacturing technology, and in particular, to an epitaxial growth method and an epitaxial wafer.

BACKGROUND

[0003] A heavily doped substrate is a key material in semiconductor manufacturing. In the heavily doped substrate, by introducing a high concentration of doping elements into a silicon substrate, the silicon substrate electrical properties are altered, thereby providing a foundation for the manufacture of high-performance semiconductor devices.

[0004] For a heavily doped substrate without a back-seal film, such as a Low Temperature Oxide (LTO) film, gas-phase autodoping is likely to occur during an epitaxial growth process. Specifically, due to the high doping level of the heavily doped substrate, under the high temperatures of the epitaxial process, the dopant in the substrate is prone to being released from its backside into the reactor chamber, and may subsequently incorporate into the growing epitaxial layer along with the reaction gas.

[0005] Gas-phase autodoping can result in the resistivity at the edge of the grown epitaxial layer being lower than that at its center, thereby reducing the resistivity uniformity across the entire epitaxial layer and ultimately impacting the quality of an epitaxial wafer.

SUMMARY

[0006] This section provides a general overview of the present disclosure, and is not a comprehensive disclosure of the full scope or all features of the present disclosure.

[0007] An object of the present disclosure is to provide an epitaxial growth method capable of improving the resistivity uniformity of an epitaxial layer formed on a heavily doped substrate

without a back-seal film.

[0008] To achieve the above object, according to an aspect of the present disclosure, an epitaxial growth method for a heavily doped substrate without a back-seal film is provided, including:

placing the heavily doped substrate on a susceptor of a reactor chamber;

introducing main hydrogen gas into the reactor chamber via a first gas inlet, and introducing auxiliary hydrogen gas into a region of the reactor chamber located below the susceptor via a second gas inlet;

baking the reactor chamber at a predetermined temperature; and

introducing a reaction gas into the reactor chamber via the first gas inlet, to form an epitaxial layer on the heavily doped substrate by a deposition reaction,

wherein at least during the baking and the deposition reaction, a flow rate of the main hydrogen gas is greater than or equal to 55 standard liter per minute (slm), or a flow rate of the auxiliary hydrogen gas is less than or equal to 18 slm.

[0009] In some embodiments, at least during the baking and the deposition reaction, the flow rate of the main hydrogen gas is greater than or equal to 55 slm, and the flow rate of the auxiliary hydrogen gas is less than or equal to 18 slm.

[0010] In some embodiments, in the case that at least during the baking and the deposition reaction, the flow rate of the main hydrogen gas is greater than or equal to 55 slm, the flow rate of the main hydrogen gas is in a range from 55 slm to 65 slm, and the flow rate of the auxiliary hydrogen gas is greater than or equal to 13 slm.

[0011] In some embodiments, in the case that at least during the baking and the deposition reaction, the flow rate of the auxiliary hydrogen gas is less than or equal to 18 slm, the flow rate of the auxiliary hydrogen gas is in a range from 13 slm to 18 slm, and the flow rate of the main hydrogen gas is less than or equal to 65 slm.

[0012] In some embodiments, at least during the baking and the deposition reaction, the flow rate of the main hydrogen gas is in a range from 55 slm to 65 slm, and the flow rate of the auxiliary hydrogen gas is in a range from 13 slm to 18 slm.

[0013] In some embodiments, at least during the baking and the deposition reaction, the flow rate of the main hydrogen gas is 60 slm, and the flow rate of the auxiliary hydrogen gas is 15 slm.

[0014] In some embodiments, the predetermined temperature is in a range from 1130°C to 1150°C, and a duration of the baking is in a range from 80 seconds to 100 seconds.

[0015] In some embodiments, a temperature of the deposition reaction is in a range from 1110°C to 1118°C.

[0016] According to another aspect of the present disclosure, an epitaxial wafer is provided, which is produced by a heavily doped substrate without a back-seal film using the epitaxial growth method according to any of the above embodiments, wherein resistivity uniformity of the epitaxial layer of the epitaxial wafer is less than 2.5%.

[0017] According to another aspect of the present disclosure, an epitaxial wafer is also provided, which is produced by a heavily doped substrate without a back-seal film using the epitaxial growth method according to some of the above-mentioned embodiments, wherein resistivity uniformity of the epitaxial layer of the epitaxial wafer is less than 2.5%, and a Site Front Quotient Range (SFQR) of the epitaxial wafer is less than or equal to 30 nm.

[0018] According to the above technical solution, at least in the baking stage and the deposition stage, the flow rate of the main hydrogen gas is enabled to be greater than or equal to 55 slm, or the flow rate of the auxiliary hydrogen gas is enabled to be less than or equal to 18 slm. Base on this, the escape of dopants released from the backside and edges of the substrate to its front side is effectively suppressed, thereby reducing gas-phase autodoping and improving the resistivity uniformity of the epitaxial layer formed on the substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] The features and advantages of the embodiments of the present disclosure will become more readily understood from the following description with reference to the accompanying drawings. The drawings are not to scale and certain features may be enlarged or reduced to show details of specific components. In the drawings:

[0020] FIG. 1 is a schematic diagram illustrating an autodoping process of a heavily doped substrate during an epitaxial process, wherein a susceptor and a portion of a substrate supported by the susceptor are shown;

[0021] FIG. 2 is a flowchart of an epitaxial growth method according to an embodiment of the present disclosure;

[0022] FIG. 3 is a top view showing a schematic structure of a reactor chamber.

[0023] In the drawings, the same or corresponding technical features or components are represented by the same or corresponding reference numerals.

DETAILED DESCRIPTION

[0024] The present disclosure will be described in detail below with reference to the

accompanying drawings by means of exemplary embodiments. It should be noted that the following detailed description of the present disclosure is only for illustrative purposes and is by no means limiting of the present disclosure.

[0025] It should also be noted that, for the sake of clarity, not all features of specific embodiments are described and shown in the description and drawings. Furthermore, to prevent unnecessary details from obscuring the technical solutions of the present disclosure, only the device structures and method steps that are closely related thereto are described and illustrated in the specification and drawings. Other details that are less relevant to the technical content of the present disclosure and that are known to those skilled in the art have been omitted.

[0026] Typically, the epitaxial growth process may include a substrate loading stage, a stabilization stage, a temperature ramp-up stage, a baking stage, a deposition stage, a cleaning stage and a cooling stage.

[0027] Specifically, in the substrate loading stage, the substrate is placed on the susceptor of the reactor chamber for subsequent epitaxial growth thereon; in the stabilization stage, the reactor chamber is heated to a first temperature and hydrogen is introduced into the reactor chamber to remove impurity gases in the reactor chamber and on the substrate; in the temperature ramp-up stage, the temperature of the reactor chamber is further increased to a second temperature; in the baking stage, the reactor chamber is maintained at the second temperature for a certain period of time; in the deposition stage, a reaction gas, such as trichlorosilane (TCS), is introduced into the reactor chamber to form an epitaxial layer on the substrate by a chemical deposition reaction at the second temperature; in the cleaning and cooling stages, the introduction of reaction gases into the reactor chamber is stopped, and the residual reaction gases and by-products in the chamber are removed by hydrogen gas, and the temperature of the reactor chamber is reduced in preparation for unloading the resulting epitaxial wafer.

[0028] A heavily doped substrate without a back-seal film, such as an LTO film, is prone to autodoping during the epitaxial growth. Referring to FIG. 1, autodoping is categorized into two types: solid-phase autodoping (as indicated by the hollow arrow E1 in FIG. 1) and gas-phase autodoping (as indicated by the hollow arrow E2 in FIG. 1). Solid-phase autodoping refers to the phenomenon where, under the high temperature of the epitaxial process, the dopant F in the substrate 200 placed on the susceptor 100 diffuses upward from the substrate 200 into the epitaxial layer 201. Gas-phase autodoping refers to the phenomenon where, under the high temperature of the epitaxial process, the dopant F in the substrate 200 is released from the backside and edges of the substrate 200 into the reactor chamber 300, and then re-incorporated into the epitaxial layer

201 along with the reaction gas (as indicated by the hollow arrow E3 in Figure 1).

[0029] Gas-phase autodoping may cause the resistivity at the edges of the grown epitaxial layer to be lower than that of the center of the grown epitaxial layer. Even in the case that the doping concentration in the substrate is excessively high and the resistivity of the entire epitaxial layer is affected, the edge of the epitaxial layer still exhibits the most severe resistivity degradation. This degrades the resistivity uniformity of the entire epitaxial layer, thus adversely affecting the quality of the epitaxial wafer.

[0030] In this regard, according to an embodiment of the present disclosure, a method for epitaxial growth of a heavily doped substrate without a back-seal film is provided. The epitaxial growth method is described in detail below with reference to FIG. 2 and FIG. 3.

[0031] As shown in FIG. 2, the epitaxial growth method includes:

step S1: placing the heavily doped substrate on a susceptor of a reactor chamber;

step S2: introducing main hydrogen gas into the reactor chamber via a first gas inlet, and introducing auxiliary hydrogen gas into a region of the reactor chamber located below the susceptor via a second gas inlet;

step S3: baking the reactor chamber at a predetermined temperature; and

step S4: introducing a reaction gas into the reactor chamber via the first gas inlet, to form an epitaxial layer on the heavily doped substrate by a deposition reaction,

wherein at least during the baking and the deposition reaction, a flow rate of the main hydrogen gas is greater than or equal to 55 standard liter per minute (slm), or a flow rate of the auxiliary hydrogen gas is less than or equal to 18 slm.

[0032] Referring to FIG. 3, the reactor chamber 10 typically includes two gas inlets, that is, a first gas inlet 11 and a second gas inlet 12. In FIG. 3, the direction of the first gas inlet 11 is exemplarily shown as being orthogonal to the direction of the second gas inlet 12. The first gas inlet 11, also commonly referred to as a main gas inlet, is used to supply gas to the main region of the reactor chamber 10, that is, primarily to the region above the heavily doped substrate 1 placed on the susceptor 20. The gas includes hydrogen (commonly referred to as main hydrogen gas (main H₂)), reaction gas, etc. The second gas inlet 12, also commonly referred to as an auxiliary gas inlet, primarily supplies gas to the region of the reactor chamber 10 below the susceptor 20. The gas includes hydrogen gas (commonly referred to as auxiliary hydrogen gas (slit H₂)). The flow rates of the gases introduced through the first gas inlet 11 and the second gas inlet 12 can be controlled, for example, by valves.

[0033] The introduction of the main hydrogen gas and auxiliary hydrogen gas into the reactor

chamber 10 continues until after step S4, for example, until the cleaning and cooling stages of the epitaxial growth process mentioned above. Here, the hydrogen gas can be used as a purge gas, for example, in step S2 and the cleaning and cooling stages, and as a carrier gas for the reaction gas, for example, in step S4.

[0034] In step S3 and step S4, the flow rate of the main hydrogen gas is controlled to be greater than or equal to 55 slm, or the flow rate of the auxiliary hydrogen gas is controlled to be less than or equal to 18 slm.

[0035] This is because, compared to other process stages of the epitaxial growth process, the temperature at the baking stage and the deposition stage is higher, for example, above 1120°C. Furthermore, at the end of the deposition stage, the growth of the epitaxial layer is completed. Therefore, during the baking stage and the deposition stage, the dopant in the substrate 1 is more likely to be released from its backside and edges, resulting in gas-phase autodoping, thereby adversely affecting the resistivity uniformity of the epitaxial layer formed on the substrate 1. However, the inventors have discovered that, during the baking stage and the deposition stage, when the flow rate of the main hydrogen gas is greater than or equal to 55 slm, or when the flow rate of the auxiliary hydrogen gas is less than or equal to 18 slm, the dopant released from the backside and edges of the substrate 1 cannot escape to the front side of the substrate 1. Instead, it is released through the holes penetrating the susceptor 20 located beneath the substrate 1. As a result, the gas-phase autodoping can be reduced, thereby improving the resistivity uniformity of the epitaxial layer formed on the substrate 1.

[0036] Furthermore, it should be understood that, in process stages of the epitaxial growth method other than the baking and deposition stages, the flow rate of the main hydrogen gas may also be greater than or equal to 55 slm, or the flow rate of the auxiliary hydrogen gas may also be less than or equal to 18 slm.

[0037] In other words, the flow rate of the main hydrogen gas may also be set to greater than or equal to 55 slm, or the flow rate of the auxiliary hydrogen gas may also be set to less than or equal to 18 slm, in one or more process stages of the epitaxial growth method other than the baking stage and the deposition stage. For example, this may be done throughout the entire epitaxial process, more specifically, from the start of introducing the main hydrogen gas and the auxiliary hydrogen gas into the reactor chamber 10 until their introduction is stopped.

[0038] It should be understood that the reasons for determining flow ranges of the main hydrogen gas and the auxiliary hydrogen gas are similar to those discussed previously, and will not be repeated here.

[0039] By introducing the main hydrogen gas and the auxiliary hydrogen gas in the flow ranges into the reactor chamber in the process stages of the epitaxial growth method other than the baking stage and the deposition stage, the escape of the released dopant to the front side of the substrate can be effectively suppressed in stages where the dopant released from the backside and edges of the substrate is likely to occur, that is, stages with higher temperature that cause the dopant in the substrate to be released from the backside and the edges. This enables a more effective reduction of the gas-phase autodoping and, consequently, a more significant improvement in the resistivity uniformity of the epitaxial layer formed on the substrate.

[0040] In some embodiments, at least during the baking and the deposition reaction, the flow rate of the main hydrogen gas may be greater than or equal to 55 slm and the flow rate of the auxiliary hydrogen gas may be less than or equal to 18 slm.

[0041] When the flow rate of the main hydrogen gas is greater than or equal to 55 slm, and when the flow rate of the auxiliary hydrogen gas is less than or equal to 18 slm, the escape of the dopant released from the backside and edges of the substrate to the front side of the substrate can be suppressed. Furthermore, when the flow rates of the main and auxiliary hydrogen gases simultaneously meet the above respective conditions, the suppression of the dopant escape from the backside and edges of the substrate is more effective compared to situations where only one of the flow rates of the main and auxiliary hydrogen gases meets the above respective condition. This enables a more effective reduction of the gas-phase autodoping and, consequently, a more significant improvement in the resistivity uniformity of the epitaxial layer formed on the substrate.

[0042] In some embodiments, in the case that the flow rate of the main hydrogen gas is greater than or equal to 55 slm at least during the baking and the deposition reaction, the flow rate of the main hydrogen gas may be in a range from 55 slm to 65 slm, and the flow rate of the auxiliary hydrogen gas may be greater than or equal to 13 slm.

[0043] This is because when the flow rate of the main hydrogen is greater than or equal to 55 slm, it improves the resistivity uniformity of the epitaxial layer formed on the substrate, for reasons similar to those stated previously. Furthermore, when the flow rate of the main hydrogen gas is greater than 65 slm or the flow rate of the auxiliary hydrogen gas is less than 13 slm, the surface flatness of the resulting epitaxial wafer deteriorates. In other words, by maintaining the flow rates of the main hydrogen gas and the auxiliary hydrogen gas within the above ranges, it is possible to not only improve the resistivity uniformity of the epitaxial layer but also to achieve good surface flatness of the epitaxial wafer.

[0044] In some embodiments, in the case that the flow rate of the auxiliary hydrogen gas is less

than or equal to 18 slm at least during the baking and the deposition reaction, the flow rate of the auxiliary hydrogen gas may be in a range from 13 slm to 18 slm, and the flow rate of the main hydrogen gas may be less than or equal to 65 slm.

[0045] This is because, when the flow rate of the slit hydrogen is less than or equal to 18 slm, it improves the resistivity uniformity of the epitaxial layer formed on the substrate, for reasons similar to those stated previously. Furthermore, when the flow rate of the auxiliary hydrogen gas is less than 13 slm or the flow rate of the main hydrogen gas is greater than 65 slm, the surface flatness of the resulting epitaxial wafer deteriorates. In other words, by maintaining the flow rates of the main hydrogen gas and the auxiliary hydrogen gas within the above ranges, it is possible to not only improve the resistivity uniformity of the epitaxial layer but also to achieve good surface flatness of the epitaxial wafer.

[0046] In some embodiments, at least during the baking and the deposition reaction, the flow rate of the main hydrogen gas may be in a range from 55 slm to 65 slm, and the flow rate of the auxiliary hydrogen gas may be in a range from 13 slm to 18 slm.

[0047] In this case, since the flow rate of the main hydrogen gas is greater than or equal to 55 slm and the flow rate of the auxiliary hydrogen gas is less than or equal to 18 slm, a more effective suppression of the dopant escape from the backside and the edges of the substrate to the front side is achieved compared to the situation where only one of the gases meets its respective condition. This enables more significant improvement in the resistivity uniformity of the epitaxial layer formed on the substrate. Furthermore, since the flow rate of the main hydrogen gas is less than or equal to 65 slm and the flow rate of the auxiliary hydrogen gas is greater than or equal to 13 slm, the resulting epitaxial wafer can achieve good surface flatness.

[0048] In some embodiments, the temperature of the deposition reaction in step S4 may be in a range from 1110°C to 1118°C.

[0049] This is because when the temperature of the deposition reaction is below 1110°C, the resistivity uniformity of the resulting epitaxial wafer deteriorates; when the temperature of the deposition reaction is above 1118°C, the surface flatness of the epitaxial layer formed on the substrate deteriorates. By maintaining the temperature of the deposition reaction within the range of 1110°C to 1118°C, both improved resistivity uniformity of the epitaxial layer formed on the substrate and good surface flatness of the epitaxial wafer can be achieved.

[0050] In addition, the autodoping also affects the target resistivity value of each epitaxial layer formed on the substrate obtained from different positions of a crystal ingot.

[0051] The dopant concentration within the crystal ingot can vary both longitudinally and

radially. Consequently, substrates obtained from different locations on the crystal ingot may also have different dopant concentrations. Consequently, when the autodoping occurs, the target resistivity values of the epitaxial layers formed on the substrates obtained from different locations on the crystal ingot can differ, leading to significant variations in the resistance of the final product obtained from that crystal ingot.

[0052] In this regard, in some embodiments, the predetermined temperature for baking in step S3 may be in a range from 1130°C to 1150°C, and the duration of baking may be in a range from 80 seconds to 100 seconds.

[0053] This is because when the predetermined baking temperature is below 1130°C, the outward release of the dopant from the substrate proceeds slowly, making it difficult to ensure the early release of the dopant from the outermost layer of the substrate (including surfaces of the backside, the front side, and the edges) during the baking stage. Conversely, when the predetermined baking temperature is above 1150°C, the haze defect is more likely to occur. Furthermore, when a duration of the baking is less than 80 seconds, it is also difficult to accelerate the outward release of the dopant from the substrate, which is not conducive to the early release of the dopant from the outermost layer of the substrate during the baking stage. When the duration of the baking is greater than 100 seconds, the haze defect is also more likely to occur.

[0054] When the predetermined baking temperature is in a range from 1130°C to 1150°C and the duration of the baking is in a range from 80 seconds to 100 seconds, the tendency of the dopant in the substrate to be released outward can be accelerated. This promotes the early release of the dopant from the outermost surface of the substrate during the baking stage, allowing the dopant to fully volatilize before the deposition step S4. As a result, the autodoping in the deposition stage can be reduced, thereby reducing the influence of the difference in dopant concentration on the resistivity of the epitaxial layers formed on each of the substrates obtained from different positions of the crystal ingot. This reduces the variation in the target resistivity values of the formed epitaxial layers, and thus lessens the difference of the resistances of the final product obtained from the crystal ingot. In addition, when the predetermined baking temperature is in a range from 1130°C to 1150°C and the duration of the baking is in a range from 80 seconds to 100 seconds, the risk of haze can also be avoided.

[0055] Through the above epitaxial growth method, the epitaxial wafer can be produced. In the embodiment of the present disclosure, the resistivity uniformity of the epitaxial layer of the epitaxial wafer can be less than 8.5%, and can be further less than 2.5%.

[0056] In some embodiments, the resistivity uniformity of the epitaxial layer of the epitaxial

wafer may be less than 2.5%, and a Site Front Quotient Range (SFQR) of the epitaxial wafer after polishing may be less than or equal to 30 nm.

[0057] The resistivity uniformity herein refers to the consistency of resistivity at different locations on the epitaxial layer, and can be measured using a variety of methods, including four-point probe testing and Hall effect measurement, among others. In the present disclosure, resistivity uniformity may be determined, for example, by the following procedure: first, excluding a 5 mm zone from the edge of the epitaxial layer, samples are taken at one point at the center of the epitaxial layer, four points at half the radius, and four points at the edge. Then, the resistivity uniformity is calculated as the ratio of the difference between the maximum resistivity and minimum resistivity among these sampling points to the sum of the maximum resistivity and minimum resistivity.

[0058] <Preliminary Study on Epitaxial Growth Method>

[0059] The epitaxial wafers according to examples A1 to A3 and comparative examples A1 to A5 are produced using the epitaxial growth method described above. These epitaxial wafers are produced using identical process conditions, except for the flow rates of the main and auxiliary hydrogen gases. Specifically, during the stabilization stage, the heating lamp power is 40 kW, and the heating time is 10 seconds. During the temperature ramp-up stage, the reactor chamber temperature is raised to 1120°C. During the baking stage, the temperature is maintained at 1120°C for 30 seconds. During the deposition stage, the temperature is maintained at 1120°C with a TCS flow rate of 8 slm. During the cleaning stage, the temperature is maintained at 1120°C for 10 seconds. During the cooling stage, the heating lamp power is 5 kW, and the cooling time is 10 seconds. Throughout the entire process, no slit gases such as hydrogen chloride (HCl) are introduced.

[0060] Table 1

item	main H ₂ (slm)	slit H ₂ (slm)	resistivity uniformity	SFQR (nm)
example a1	60	20	7.64%	30
example a2	50	15	8.23%	29
example a3	60	15	6.14%	30
comparative example a1	50	20	14.17%	28
comparative example a2	60	10	6.52%	35
comparative	70	15	5.91%	34

example a3				
comparative example a4	70	10	5.85%	38
comparative example a5	80	10	5.67%	45

[0061] Table 1 shows the flow rates of the main hydrogen gas and the auxiliary hydrogen gas introduced into the reactor chamber during the baking stage and the deposition stage for the epitaxial wafers produced according to examples A1 to A3 and comparative examples A1 to A5, as well as the corresponding resistivity uniformity of the epitaxial layer of the produced epitaxial wafers and the corresponding flatness of the epitaxial wafers represented by the SFQR.

[0062] In examples A1 and A3, the flow rate of the main hydrogen gas is greater than 55 slm, and in examples A2 and A3, the flow rate of the auxiliary hydrogen gas is less than 18 slm. In all these cases, the resistivity uniformity of the epitaxial layer is less than 8.5%. In comparative example A1, the flow rate of the main hydrogen gas is less than 55 slm and the flow rate of the auxiliary hydrogen gas is greater than 18 slm, resulting in a resistivity uniformity of the epitaxial layer of 14.17%, which is higher than 8.5%. Therefore, when the flow rate of the main hydrogen gas is greater than or equal to 55 slm, or the flow rate of the auxiliary hydrogen gas is less than or equal to 18 slm, the resistivity uniformity of the epitaxial layer formed on the substrate can be improved.

[0063] Furthermore, in example A3, the flow rate of main hydrogen gas is greater than 55 slm and the flow rate of the auxiliary hydrogen gas is less than 18 slm, resulting in an epitaxial layer with a resistivity uniformity of 6.14%. In example A1, the flow rate of main hydrogen gas is greater than 55 slm, but the flow rate of the auxiliary hydrogen gas is greater than 18 slm. In example A2, the flow rate of the auxiliary hydrogen gas is less than 18 slm, but the flow rate of the main hydrogen gas is less than 55 slm. The resistivity uniformity of the epitaxial layer in examples A1 and A2 is 7.64% and 8.23%, respectively, both higher than 6.14%. Therefore, when the flow rate of main hydrogen gas is greater than 55 slm and the flow rate of the auxiliary hydrogen gas is less than 18 slm, the resistivity uniformity of the epitaxial layer formed on the substrate can be improved more effectively.

[0064] In examples A1 and A3, the flow rate of the main hydrogen gas is in a range from 55 slm to 65 slm, and the flow rate of the auxiliary hydrogen gas is greater than 13 slm. The resistivity uniformity of the epitaxial layer in both cases is less than 8.5%, and the SFQR of the epitaxial

wafer is 30 nm. In comparative example A1, although the flow rate of the auxiliary hydrogen gas is greater than 13 slm, the flow rate of the main hydrogen gas is less than 55 slm; while the SFQR of the epitaxial wafer is less than 30 nm, the resistivity uniformity of the epitaxial layer is greater than 8.5%. In comparative example A2, the flow rate of the main hydrogen gas is in a range from 55 slm to 65 slm, but the flow rate of the auxiliary hydrogen gas is less than 13 slm. The resistivity uniformity of the epitaxial layer is less than 8.5%, but the SFQR of the epitaxial wafer is greater than 30 nm. In comparative example A3, the flow rate of the auxiliary hydrogen gas is greater than 13 slm, but the flow rate of main hydrogen gas is greater than 65 slm. The resistivity uniformity of the epitaxial layer is less than 8.5%, but the SFQR of the epitaxial wafer is greater than 30 nm. In comparative examples A4 and A5, the flow rate of the main hydrogen gas is greater than 65 slm and the flow rate of the auxiliary hydrogen gas is less than 13 slm. The resistivity uniformity of the epitaxial layer is less than 8.5%, but the SFQR of the epitaxial wafer is greater than 30 nm. Therefore, when the flow rate of the main hydrogen gas is in a range from 55 slm to 65 slm and the flow rate of the auxiliary hydrogen gas is greater than or equal to 13 slm, it is possible to not only improve the resistivity uniformity of the epitaxial layer but also to achieve good surface flatness of the epitaxial wafer.

[0065] In examples A2 and A3, the flow rate of the auxiliary hydrogen gas is in a range from 13 slm to 18 slm, and the flow rate of main hydrogen gas is less than 65 slm. The resistivity uniformity of the epitaxial layer in both cases is less than 8.5%, and the SFQR of the epitaxial wafer is less than or equal to 30 nm. In comparative example A1, although the flow rate of main hydrogen gas is less than 65 slm, the flow rate of the auxiliary hydrogen gas is greater than 18 slm; in addition, the SFQR of the epitaxial wafer is less than 30 nm, the resistivity uniformity of the epitaxial layer is greater than 8.5%. In comparative example A2, the flow rate of the main hydrogen gas is less than 65 slm, but the flow rate of the auxiliary hydrogen gas is less than 13 slm. The resistivity uniformity of the epitaxial layer is less than 8.5%, but the SFQR of the epitaxial wafer is greater than 30 nm. In comparative example A3, the flow rate of the auxiliary hydrogen gas is in a range from 13 slm to 18 slm, but the flow rate of the main hydrogen gas is greater than 65 slm. The resistivity uniformity of the epitaxial layer is less than 8.5%, but the SFQR of the epitaxial wafer is greater than 30 nm. In comparative examples A4 and A5, the flow rate of the main hydrogen gas is greater than 65 slm, and the flow rate of the auxiliary hydrogen gas is less than 13 slm. The resistivity uniformity of the epitaxial layer is less than 8.5%, but the SFQR of the epitaxial wafer is greater than 30 nm. Therefore, when the flow rate of the auxiliary hydrogen gas is in a range from 13 slm to 18 slm and the flow rate of the main hydrogen gas is less than 65 slm, it is possible

to not only improve the resistivity uniformity of the epitaxial layer but also to achieve good surface flatness of the epitaxial wafer.

[0066] In example A3, the flow rate of the main hydrogen gas is in a range from 55 slm to 65 slm and the flow rate of the auxiliary hydrogen gas is in a range from 13 slm to 18 slm. The resistivity uniformity of the epitaxial layer is 6.14%, and the SFQR of the epitaxial wafer is 30 nm. In example A1, the flow rate of the main hydrogen gas is in a range from 55 slm to 65 slm, but the flow rate of the auxiliary hydrogen gas is greater than 18 slm. The SFQR of the epitaxial wafer is 30 nm, but the resistivity uniformity of the epitaxial layer is greater than 6.14%. In example A2, the flow rate of the auxiliary hydrogen gas is in a range from 13 slm to 18 slm, but the flow rate of the main hydrogen gas is less than 55 slm. The SFQR of the epitaxial wafer is less than 30 nm, but the resistivity uniformity of the epitaxial layer is greater than 6.14%. Therefore, when the flow rate of the main hydrogen gas is in a range from 55 slm to 65 slm and the flow rate of the auxiliary hydrogen gas is in a range from 13 slm to 18 slm, it is possible to not only achieve good surface flatness of the resulting epitaxial wafer but also to improve the resistivity uniformity of the epitaxial layer formed on the substrate.

[0067] With the same flow rates of the main hydrogen gas and the auxiliary hydrogen gas, the epitaxial wafers according to example B1 and comparative examples B1 and B2 are produced under the same process conditions as described above for examples A1 to A3, except for the deposition temperature.

[0068] Table 2

item	deposition temperature (°C)	resistivity uniformity	SFQR (nm)
example B1	1115	5.26	29
comparative example B1	1105	7.51	27
comparative example B2	1125	4.78	38

[0069] Table 2 shows the deposition temperature used for the epitaxial wafers produced according to example B1 and comparative examples B1 and B2, as well as the corresponding resistivity uniformity of the epitaxial layers of the produced epitaxial wafers and the corresponding flatness of the epitaxial wafers represented by the SFQR.

[0070] In example B1, when the deposition temperature is in a range from 1110°C to 1118°C, the resistivity uniformity of the epitaxial layer is 5.26%, and the SFQR of the epitaxial wafer is 29nm. In comparative example B1, when the deposition temperature is below 1110°C, the SFQR of the epitaxial wafer is 27nm, but the resistivity uniformity of the epitaxial layer is 7.51%, which

is worse than 5.26%. In comparative example B2, when the deposition temperature is above 1118°C, the resistivity uniformity of the epitaxial layer is 4.78%, but the SFQR of the epitaxial wafer is 38nm, which is worse than 27nm. Therefore, when the deposition temperature is in a range from 1110°C to 1118°C, it is possible to not only improve the resistivity uniformity of the epitaxial layer formed on the substrate but also to achieve good surface flatness of the epitaxial wafer.

[0071] With the same flow rates of the main hydrogen gas and auxiliary hydrogen gas, epitaxial wafers according to example C1 and comparative examples C1 and C2 are produced under the same process conditions as described above for examples A1 to A3, except for the baking temperature.

[0072] Table 3

item	baking temperature (°C)/ baking time (s)	target resistivity (ohm.cm)			haze parameter (ppm)
		head	middle	tail	
example C1	1140/90	10.1	10.1	10.2	0.25
comparative example C1	1120/30	10.7	10.0	9.4	0.21
comparative example C2	1160/110	10.1	10.1	10.1	0.43

[0073] Table 3 shows the baking temperatures and baking times used for producing epitaxial wafers according to example C1 and comparative examples C1 and C2, using silicon substrates obtained from different positions of the crystal ingot. It also shows the target resistivity values of the epitaxial layer of the epitaxial wafers produced from silicon substrates taken from the head, the middle, and the tail of the crystal ingot, as well as the corresponding haze values.

[0074] In example C1, when the baking temperature is in a range from 1130°C to 1150°C and the baking time is in a range from 80 seconds to 100 seconds, the target resistivity values of the epitaxial wafers corresponding to the head, the middle, and the tail of the crystal ingot tend to be consistent, and the haze is 0.25ppm. In comparative example C1, when the baking temperature is below 1130°C and the baking time is less than 80 seconds, the haze is 0.21ppm; however, there are significant differences in the target resistivity values of the epitaxial wafers corresponding to the head, the middle, and the tail of the crystal ingot. In comparative example C2, the baking temperature is above 1150°C and the baking time is greater than 100 seconds; although the target

resistivity values of the epitaxial wafers corresponding to the head, the middle, and the tail of the crystal ingot tend to be consistent, the haze is 0.43ppm, which is significantly worse than 0.25ppm. Therefore, when the predetermined baking temperature is in a range from 1130°C to 1150°C and the baking time is in a range from 80 seconds to 100 seconds, not only can the difference in the target resistivity values of the epitaxial layers formed on various substrates obtained from different positions of the crystal ingot be reduced, but the risk of haze can also be avoided.

[0075] In the present disclosure, the terms "first," "second," and the like are used merely for descriptive purposes and should not be construed as limiting. Furthermore, while the present disclosure has been described with reference to the exemplary embodiments, it should be understood that the present disclosure is not limited to the specific embodiments described and illustrated in detail herein. Various modifications to the exemplary embodiments may be made by those skilled in the art without departing from the scope defined by the claims of the present disclosure.

[0076] The features mentioned and/or illustrated in the above description of the exemplary embodiments of the present disclosure may be incorporated into one or more other embodiments in same or similar manner, either in combination with features in the other embodiments or as substitutes for corresponding features therein. The technical solutions obtained by such combination or substitution should also be regarded as being within the scope of the present disclosure.

What is claimed is:

1. An epitaxial growth method for a heavily doped substrate without a back-seal film, comprising:

placing the heavily doped substrate on a susceptor of a reactor chamber;

introducing main hydrogen gas into the reactor chamber via a first gas inlet, and introducing auxiliary hydrogen gas into a region of the reactor chamber located below the susceptor via a second gas inlet;

baking the reactor chamber at a predetermined temperature; and

introducing a reaction gas into the reactor chamber via the first gas inlet, to form an epitaxial layer on the heavily doped substrate by a deposition reaction,

wherein at least during the baking and the deposition reaction, a flow rate of the main hydrogen gas is greater than or equal to 55 slm, or a flow rate of the auxiliary hydrogen gas is less than or equal to 18 slm.

2. The epitaxial growth method according to claim 1, wherein at least during the baking and the deposition reaction, the flow rate of the main hydrogen gas is greater than or equal to 55 slm, and the flow rate of the auxiliary hydrogen gas is less than or equal to 18 slm.

3. The epitaxial growth method according to claim 1, wherein in the case that at least during the baking and the deposition reaction, the flow rate of the main hydrogen gas is greater than or equal to 55 slm, the flow rate of the main hydrogen gas is in a range from 55 slm to 65 slm, and the flow rate of the auxiliary hydrogen gas is greater than or equal to 13 slm.

4. The epitaxial growth method according to claim 1, wherein in the case that at least during the baking and the deposition reaction, the flow rate of the auxiliary hydrogen gas is less than or equal to 18 slm, the flow rate of the auxiliary hydrogen gas is in a range from 13 slm to 18 slm, and the flow rate of the main hydrogen gas is less than or equal to 65 slm.

5. The epitaxial growth method according to claim 1, wherein at least during the baking and the deposition reaction, the flow rate of the main hydrogen gas is in a range from 55 slm to 65 slm, and the flow rate of the auxiliary hydrogen gas is in a range from 13 slm to 18 slm.

6. The epitaxial growth method according to claim 5, wherein at least during the baking and the deposition reaction, the flow rate of the main hydrogen gas is 60 slm, and the flow rate of the auxiliary hydrogen gas is 15 slm.

7. The epitaxial growth method according to any one of claims 1 to 6, wherein the predetermined temperature is in a range from 1130°C to 1150°C, and a duration of the baking is

in a range from 80 seconds to 100 seconds.

8. The epitaxial growth method according to any one of claims 1 to 6, wherein a temperature of the deposition reaction is in a range from 1110°C to 1118°C.

9. An epitaxial wafer, produced by the heavily doped substrate without the back-seal film using the epitaxial growth method according to any one of claims 1 to 8, wherein resistivity uniformity of the epitaxial layer of the epitaxial wafer is less than 2.5%.

10. An epitaxial wafer, produced by the heavily doped substrate without the back-seal film using the epitaxial growth method according to any one of claims 3 to 6, wherein resistivity uniformity of the epitaxial layer of the epitaxial wafer is less than 2.5%, and a Site Front Quotient Range (SFQR) of the epitaxial wafer is less than or equal to 30 nm.