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# DESCRIPTION

## TECHNICAL FIELD

**[0001]** The present invention relates to single crystal production methods using the FZ method (floating zone method or floating zone melting method) by which a single crystal ingot is grown by forming a floating zone by heating and melting a raw material crystal ingot with an induction heating coil and moving the floating zone and to silicon single crystals and, more particularly, to a single crystal production method that prevents the generation of OSFs (oxidation-induced stacking faults) and a phosphorus-doped N-type silicon single crystal.

## BACKGROUND ART

**[0002]** The FZ method is used as one of methods for producing a semiconductor single crystal, for example, a silicon single crystal that is most commonly used as a semiconductor device at present.

**[0003]** FIG. 3 is an example of a single crystal production apparatus used in an existing FZ single crystal production method. A method for producing a single crystal by using this FZ single crystal production apparatus 30 will be described.

**[0004]** First, a raw material crystal ingot 1 is held by an upper holding jig 4 of an upper shaft 3 placed in a chamber 20. On the other hand, a seed (seed crystal) 8 of a single crystal with a small diameter is held by a lower holding jig 6 of a lower shaft 5 located below the raw material crystal ingot 1.

**[0005]** Next, the raw material crystal ingot 1 is melted by an induction heating coil 7 and is fusion-bonded to the seed crystal 8. Thereafter, a neck portion 9 is formed by necking to eliminate dislocation. Then, by moving the raw material crystal ingot 1 and a grown single crystal ingot 2 downward while rotating the upper shaft 3 and the lower shaft 5, a floating zone (also called a melt zone or molten melt) 10 is formed between the raw material crystal ingot 1 and the grown single crystal ingot 2, the floating zone 10 is moved to an upper end of the raw material crystal ingot 1, and zoning is performed, whereby the grown single crystal ingot 2 is grown.

**[0006]** Incidentally, this single crystal growth is performed in an atmosphere obtained by mixing a very small amount of nitrogen gas into Ar gas, and, in order to produce an N-type FZ single crystal, Ar-based PH<sub>3</sub> gas whose amount is determined based on resistivity to be produced is fed by a nozzle for spraying doping gas (doping nozzle) 11.

**[0007]** As the induction heating coil 7 described above, a single-wound or compound-wound

induction heating coil made of copper or silver, the induction heating coil through which cooling water is circulated, is used.

**[0008]** In recent years, the need for a larger-diameter single crystal has intensified. As a result, also in the FZ method, more and more larger-diameter single crystals are being produced. However, if an N-type large-diameter FZ single crystal, in particular, a large-diameter single crystal with a diameter of 200 mm or more is produced by an existing method, when an OSF test (for example, at 1150°C, Wet O<sub>2</sub>-100 min, selective etching 4 min) is performed on a wafer cut from this crystal, OSFs are generated, which poses a problem.

**[0009]** As measures to prevent OSFs, in production of a CZ single crystal, a manufacturing method in which doping with Al (aluminum) is performed has been disclosed (refer to, for example, Patent Literature 1). However, in an FZ single crystal which is required to be a crystal with high resistivity as compared to a CZ single crystal, if doping with Al whose segregation coefficient is 0.002 and is lower than 0.35 of P (phosphorus) and 0.8 of B (boron) is performed, the in-plane resistivity distribution and the axial resistivity distribution become substantially worse, making it impossible to control resistivity, and it is difficult to perform gas doping with Al. It is for this reason that an alternative to Al doping has been sought after.

## **CITATION LIST**

### **PATENT LITERATURE**

**[0010]** Patent Literature 1: Japanese Unexamined Patent publication (Kokai) No.H8-73293

**[0011]** CN 1 865 530 A discloses a silicon ingot manufactured with the FZ method using PH<sub>3</sub> or B<sub>2</sub>H<sub>6</sub> as dopant.

**[0012]** W. von Ammon et al. report about "The impact of nitrogen on the defect aggregation in silicon" in JOURNAL OF CRYSTAL GROWTH, ELSEVIER, AMSTERDAM, NL, vol. 226, no. 1, 1 June 2001. From this document it is known that N<sub>2</sub> has the effect of limiting stacking faults and aggregation defects in silicon single crystal growth by the FZ method.

**[0013]** US 2011/0030793 A1 discloses the production of photovoltaic grade crystalline silicon by crystallization of a molten silicon feedstock.

**[0014]** US 2001/0020438 A1 concerns a method for manufacturing a dislocation-free silicon single crystal. This method includes the steps of preparing a silicon seed crystal formed of a dislocation-free single crystal having a boron concentration of  $1 \times 10^{18}$  atoms/cm<sup>3</sup> or more.

**[0015]** US 2003/0024469 A1 discloses that a silicon single crystal may be produced by

crucible-free float zone pulling, wherein the single crystal has a diameter of at least 200 mm over a length of at least 200 mm and is free of dislocations in the region of this length.

**SUMMARY OF THE INVENTION**

**[0016]** The present invention has been made in view of the problems described above and an object thereof is to provide an N-type silicon single crystal production method and an N-type silicon single crystal, the method that can prevent the generation of OSFs even when a silicon single crystal, in particular, a large-diameter silicon single crystal with a diameter of 8 inches (200 mm) or more is produced by the FZ method.

**[0017]** To solve the above-described problems, the present invention provides a method for producing an N-type silicon single crystal with a diameter of 8 inches (200 mm) or more by the FZ method, wherein the N-type silicon single crystal is produced by performing doping by using Ar-based PH<sub>3</sub> gas and Ar-based B<sub>2</sub>H<sub>6</sub> gas as doping gas, and by feeding the Ar-based B<sub>2</sub>H<sub>6</sub> gas in such a way that a B concentration in the N-type silicon single crystal to be produced becomes  $3 \times 10^{12}$  atoms/cm<sup>3</sup> or more.

**[0018]** With such a method, it is possible to produce a high-quality N-type FZ silicon single crystal in which OSFs are not generated.

**[0019]** In this case, it is possible that the doping by the Ar-based PH<sub>3</sub> gas and the Ar-based B<sub>2</sub>H<sub>6</sub> gas is performed by mixing the Ar-based PH<sub>3</sub> gas and the Ar-based B<sub>2</sub>H<sub>6</sub> gas and feeding the mixture of the gases from a nozzle for spraying doping gas, the nozzle provided near molten melt of an FZ single crystal production apparatus, or a doping gas jetting port provided below the molten melt.

**[0020]** As described above, by mixing the Ar-based PH<sub>3</sub> gas and the Ar-based B<sub>2</sub>H<sub>6</sub> gas and feeding the mixture from the nozzle for spraying doping gas, it is easy to control the B concentration with which doping is performed and it is possible to make an N-type silicon single crystal to be produced absorb B more easily, and, by mixing the Ar-based PH<sub>3</sub> gas and the Ar-based B<sub>2</sub>H<sub>6</sub> gas and feeding the mixture from the doping gas jetting port, it is possible to perform uniform doping with B and P.

**[0021]** Moreover, it is also possible that the doping by the Ar-based PH<sub>3</sub> gas and the Ar-based B<sub>2</sub>H<sub>6</sub> gas is performed by feeding the Ar-based PH<sub>3</sub> gas from a nozzle for spraying doping gas, the nozzle provided near molten melt of an FZ single crystal production apparatus, and by feeding the Ar-based B<sub>2</sub>H<sub>6</sub> gas from a doping gas jetting port provided below the molten melt.

**[0022]** As described above, by feeding the Ar-based PH<sub>3</sub> gas from the nozzle for spraying doping gas and feeding the Ar-based B<sub>2</sub>H<sub>6</sub> gas from the doping gas jetting port, it is possible to

adjust easily the resistivity by doping with P that requires a higher concentration than that of B to obtain an N-type crystal and perform uniform doping with B that is performed at a low concentration to prevent the generation of OSFs.

**[0023]** Moreover, it is possible that an N-type silicon single crystal with a diameter of 8 inches (200 mm) or more is produced by feeding the Ar-based B<sub>2</sub>H<sub>6</sub> gas in such a way that a B concentration in an N-type silicon single crystal to be produced becomes  $3 \times 10^{12}$  atoms/cm<sup>3</sup> or more.

**[0024]** With such a B concentration, even when the crystal has a large diameter of 8 inches (200 mm) or more, it is possible to obtain an adequate OSF generation-prevention effect and produce a high-quality single crystal with stability.

**[0025]** Furthermore, the present invention provides a phosphorus-doped N-type FZ silicon single crystal, wherein the phosphorus-doped N-type FZ silicon single crystal has at least a B concentration of  $3 \times 10^{12}$  atoms/cm<sup>3</sup> or more and a diameter of 8 inches (200 mm) or more.

**[0026]** While such a phosphorus-doped N-type FZ silicon single crystal is an N-type large-diameter FZ silicon single crystal, since the phosphorus-doped N-type FZ silicon single crystal is a high-quality silicon single crystal in which OSFs are not generated, this phosphorus-doped N-type FZ silicon single crystal is highly valuable as a product.

**[0027]** As described above, according to the method for producing an N type FZ silicon single crystal of the present invention, it is possible to produce stably a high-quality single crystal in which OSFs are not generated even when, in particular, the crystal has a large diameter of 8 inches (200 mm) or more.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

### **[0028]**

FIG. 1 is a schematic diagram of an example of a single crystal production apparatus using the FZ method used in a method for producing an N-type silicon single crystal of the present invention;

FIG. 2 is a schematic diagram of another example of the single crystal production apparatus using the FZ method used in the method for producing an N-type silicon single crystal of the present invention; and

FIG. 3 is a schematic diagram of an example of a single crystal production apparatus used in an existing FZ single crystal production method.

**BEST MODE FOR CARRYING OUT THE INVENTION**

**[0029]** Hereinafter, the present invention will be described more specifically.

**[0030]** As mentioned earlier, as larger-diameter single crystals have been required in recent years, more and more larger-diameter single crystals are being produced by the FZ method. However, if a large-diameter single crystal, in particular, a silicon single crystal with a diameter of 8 inches (200 mm) or more is produced by an existing manufacturing method, OSFs are generated frequently, which poses a problem.

**[0031]** The inventors of the present invention intensively studied the causes of OSFs that are generated when a large-diameter N-type silicon single crystal with a diameter of 6 inches (150 mm) or more, in particular, a diameter of 8 inches (200 mm) or more is produced by the FZ method. As a result, the inventors of the present invention have found out that, when a large-diameter single crystal is produced by the FZ method, a region in which interstitial silicon is predominant is generated on the periphery of the crystal and the interstitial silicon agglomerates together and becomes a nucleus, resulting in the generation of OSFs.

**[0032]** Thus, as a result of the inventors of the present invention focusing attention on the fact that B suppresses the generation of an interstitial silicon type dislocation cluster in the CZ method ("Silicon Technology, No. 59, The Effect of Impurities on the Grown-in Defects in CZ-Si Crystals (B, C, N, O, Sb, As, P) Kozo Nakamura, Junsuke Tomioka") and further having kept conducting experiments and the like, the inventors of the present invention have found out that, in a method for producing an FZ silicon single crystal containing no oxygen, by performing B<sub>2</sub>H<sub>6</sub> gas doping along with PH<sub>3</sub> gas doping during zoning to produce an N-type FZ single crystal and adding a very small amount of B to the single crystal, it is possible to suppress the generation of an interstitial silicon type dislocation cluster which can be an OSF nucleus and prevent the generation of OSFs, and have completed the present invention.

**[0033]** Hereinafter, an embodiment of the present invention will be described with reference to the drawings, but the present invention is not limited thereto.

**[0034]** FIGs. 1 and 2 are schematic diagrams of examples of a single crystal production apparatus used in a method for producing an N type FZ silicon single crystal of the present invention.

**[0035]** An FZ single crystal production apparatus 40 of FIG. 1 includes a chamber 20 that houses a raw material crystal ingot 1 and a grown single crystal ingot 2 and an induction heating coil 7 serving as a heat source for forming a floating zone (molten melt) 10 between the raw material crystal ingot 1 and the grown single crystal ingot 2. In addition, from a nozzle for spraying doping gas (doping nozzle) 11, Ar-based PH<sub>3</sub> gas for producing an N-type silicon single crystal and Ar-based B<sub>2</sub>H<sub>6</sub> gas for preventing the generation of OSFs are mixed and fed.

**[0036]** In an FZ single crystal production apparatus 41 of FIG. 2, from the doping nozzle 11, Ar-based  $\text{PH}_3$  gas for producing an N-type silicon single crystal is fed, and, from a doping gas jetting port 12 located below the molten melt 10, Ar-based  $\text{B}_2\text{H}_6$  gas for preventing the generation of OSFs is fed. The other configurations are almost the same as those of FIG. 1.

**[0037]** In the present invention, for example, by using such a single crystal production apparatus 40, an N-type silicon single crystal is produced in the following manner.

**[0038]** First, a portion of the silicon raw material ingot 1, the portion from which melting is started, is manufactured into the shape of a cone, and etching is performed on the surface to remove mechanical damage. Then, the silicon raw material ingot 1 is housed in the chamber 20 of the FZ single crystal production apparatus 40 depicted in FIG. 1 and is fixed to an upper holding jig 4 of an upper shaft 3 placed in the chamber 20 with a screw or the like. On the other hand, a seed crystal 8 is attached to a lower holding jig 6 of a lower shaft 5.

**[0039]** Next, a lower end of the cone portion of the silicon raw material ingot 1 is preliminarily heated by a carbon ring (not shown). Then, Ar gas containing nitrogen gas is fed from a lower part of the chamber 20 and the gas is exhausted from an upper part of the chamber to set the pressure at 0.15 MPa, the rate of flow of the Ar gas at 20 to 50 l/min, and the concentration of nitrogen in the chamber at 0.1 to 0.5%, for example. In addition, after heating and melting the silicon raw material ingot 1 by the induction heating coil 7, the tip of the cone portion is fusion-bonded to the seed crystal 8, dislocation is eliminated by a neck portion 9, and by moving the silicon raw material ingot 1 and the grown single crystal ingot 2 downward at a rate of 1 to 5 mm/min, for example, while rotating the upper shaft 3 and the lower shaft 5, the molten melt 10 is moved to an upper end of the silicon raw material ingot 1 and zoning is performed, whereby the silicon single crystal ingot 2 is grown.

**[0040]** At this time, it is preferable that the growth of a single crystal is performed by displacing the upper shaft 3 which becomes a rotation center at the time of the growth of the silicon raw material ingot 1 from the lower shaft 5 which becomes a rotation center of the single crystal at the time of single crystallization (making the upper shaft 3 and the lower shaft 5 eccentric). By displacing one central axis from the other central axis, it is possible to allow a molten portion to be agitated at the time of single crystallization and thereby it is possible to homogenize the quality of a single crystal to be produced. The amount of eccentricity may be set in accordance with the diameter of a single crystal.

**[0041]** Moreover, to obtain predetermined N-type resistivity during zoning, Ar-based  $\text{PH}_3$  gas and Ar-based  $\text{B}_2\text{H}_6$  gas for preventing OSFs are mixed and fed from the doping nozzle 11.

**[0042]** At this time, the concentration of  $\text{PH}_3$  in doping gas is set to be higher than the  $\text{B}_2\text{H}_6$  concentration such that the conductivity type of a silicon single crystal to be obtained becomes N type. The ratio of concentration between  $\text{PH}_3$  and  $\text{B}_2\text{H}_6$  or a concentration difference may be

determined such that a silicon single crystal to be produced has required resistivity.

**[0043]** In addition to this, as depicted in FIG. 2, when the single crystal production apparatus 41 described above, for example, is used, the Ar-based  $B_2H_6$  gas may be fed from the doping gas jetting port 12 located below the molten melt, or, for example, the Ar-based  $PH_3$  gas and the Ar-based  $B_2H_6$  gas can also be mixed and fed from the doping gas jetting port 12.

**[0044]** At this time, to produce a large-diameter N-type silicon single crystal with a diameter of 8 inches (200 mm) or more without problems, it is preferable to feed the Ar-based  $B_2H_6$  gas in such a way that the B concentration in an N-type silicon single crystal to be produced becomes  $3 \times 10^{12}$  atoms/cm<sup>3</sup> or more. Therefore, it is necessary simply to feed Ar-based  $PH_3$  at a concentration at which a B concentration of  $3 \times 10^{12}$  atoms/cm<sup>3</sup> or more in a silicon single crystal is cancelled out to obtain an N-type silicon single crystal with desired resistivity.

**[0045]** The N-type silicon single crystal produced in this manner contains a B concentration of  $3 \times 10^{12}$  atoms/cm<sup>3</sup> or more, and, even when the crystal has a large-diameter N-type silicon single crystal with a diameter of 8 inches (200 mm) or more, it is possible to prevent the generation of OSFs. Therefore, the present invention can provide a high-quality phosphorus-doped N-type FZ silicon single crystal.

**[0046]** Incidentally, the upper limit of the B concentration in the N-type silicon single crystal may be adjusted in such a way that the upper limit is up to the solubility limit at which a single crystal structure can be maintained with both P for producing an N-type silicon single crystal and B for preventing OSFs and desired resistivity is obtained at a concentration that is lower than that concentration.

## EXAMPLES

**[0047]** Hereinafter, the present invention will be described more specifically with examples and a comparative example, but the present invention is not limited to these examples.

### (Example 1)

**[0048]** By using a CZ silicon single crystal with a resistivity of 1000 Qcm or more and a diameter of 150 mm as a silicon raw material ingot, zoning was performed by the FZ method, whereby an FZ silicon single crystal with a diameter of 205 mm and a straight body length of 70 cm, the FZ silicon single crystal with a target set at N type and 50 Qcm, was produced.

**[0049]** When this silicon single crystal was produced, the single crystal production apparatus depicted in FIG. 1 was used.

**[0050]** As the induction heating coil, a parallel coil having an internal first heating coil with an outside diameter of 160 mm and an outer second heating coil with an outside diameter of 280 mm was used, the furnace pressure was set at 0.19 MPa, the rate of flow of Ar gas was set at 50 L/min, the concentration of nitrogen gas in the chamber was set at 0.1%, the growth rate was set at 2.0 mm/min, and the amount of eccentricity was set at 12 mm. Moreover, a quartz plate for preventing discharge was inserted into a slit of the induction heating coil.

**[0051]** From the doping nozzle, Ar-based PH<sub>3</sub> gas at a 0.35 to 0.45 ppma concentration was fed at a flow rate of 1000 cc/min and Ar-based B<sub>2</sub>H<sub>6</sub> gas at a 0.004 to 0.02 ppma concentration was fed at a flow rate of 500 cc/min.

**[0052]** In this manner, eight silicon single crystals produced by the FZ method were obtained without any trouble without the generation of dislocation during the growth.

**[0053]** As a result of an OSF test (1150°C Wet O<sub>2</sub>-100 min, selective etching 4 min) having been performed on the wafers cut from the cone side, the central part, and the tail side of the crystals thus obtained, OSFs were not generated in all of the crystals. Moreover, as a result of measurement of the B concentration in a crystal having being performed on the tail-side samples by the PL method, the B concentration was 4.07×10<sup>12</sup> to 8.15×10<sup>12</sup> atoms/cm<sup>3</sup> (samples Nos. 10 to 17 in Table 1). Furthermore, the target resistivity was also obtained.

#### **(Example 2)**

**[0054]** By using a CZ silicon single crystal with a resistivity of 1000 Qcm or more and a diameter of 150 mm as a silicon raw material ingot, zoning was performed by the FZ method, whereby an FZ silicon single crystal with a diameter of 205 mm and a straight body length of 70 cm, the FZ silicon single crystal with a target set at N type and 50 Qcm, was produced.

**[0055]** When this silicon single crystal was produced, the single crystal production apparatus depicted in FIG. 2 was used.

**[0056]** As the induction heating coil, a parallel coil having an internal first heating coil with an outside diameter of 160 mm and an outer second heating coil with an outside diameter of 280 mm was used, the furnace pressure was set at 0.19 MPa, the rate of flow of Ar gas was set at 50 L/min, the concentration of nitrogen gas in the chamber was set at 0.1%, the growth rate was set at 2.0 mm/min, and the amount of eccentricity was set at 12 mm. Moreover, a quartz plate for preventing discharge was inserted into a slit of the induction heating coil.

**[0057]** From the doping nozzle, Ar-based PH<sub>3</sub> gas at a 0.35 to 0.45 ppma concentration was fed at a flow rate of 1000 cc/min and, from the doping gas jetting port located below the molten melt, Ar-based B<sub>2</sub>H<sub>6</sub> gas at a 0.002 to 0.06 ppma concentration was fed at a flow rate of 1000

cc/min.

**[0058]** In this manner, ten silicon single crystals produced by the FZ method were obtained without any trouble without the generation of dislocation during the growth.

**[0059]** As a result of an OSF test (1150°C Wet O<sub>2</sub>-100 min, selective etching 4 min) having been performed on the wafers cut from the cone side, the central part, and the tail side of the crystals thus obtained, OSFs were not generated in all of the crystals. Moreover, as a result of measurement of the B concentration in a crystal having being performed on the tail-side samples by the PL method, the B concentration was  $3.22 \times 10^{12}$  to  $8.05 \times 10^{12}$  atoms/cm<sup>3</sup> (samples Nos. 18 to 27 in Table 1). Furthermore, the target resistivity was also obtained.

#### **(Comparative Example)**

**[0060]** By using a CZ silicon single crystal with a resistivity of 1000 Ωcm or more and a diameter of 150 mm as a silicon raw material ingot, zoning was performed by the FZ method, whereby an FZ silicon single crystal with a diameter of 205 mm and a straight body length of 70 cm, the FZ silicon single crystal with a target set at N type and 50 Ωcm, was produced.

**[0061]** When this silicon single crystal was produced, the single crystal production apparatus depicted in FIG. 3 was used.

**[0062]** As the induction heating coil, a parallel coil having an internal first heating coil with an outside diameter of 160 mm and an outer second heating coil with an outside diameter of 280 mm was used, the furnace pressure was set at 0.19 MPa, the rate of flow of Ar gas was set at 50 L/min, the concentration of nitrogen gas in the chamber was set at 0.1%, the growth rate was set at 2.0 mm/min, and the amount of eccentricity was set at 12 mm. Moreover, a quartz plate for preventing discharge was inserted into a slit of the induction heating coil.

**[0063]** From the doping nozzle, Ar-based PH<sub>3</sub> gas at a 0.35 to 0.45 ppm concentration was fed at a flow rate of 1000 cc/min.

**[0064]** In this manner, nine silicon single crystals produced by the FZ method were obtained without any trouble without the generation of dislocation during the growth.

**[0065]** As a result of an OSF test (1150°C Wet O<sub>2</sub>-100 min, selective etching 4 min) having been performed on the wafers cut from the cone side, the central part, and the tail side of the crystals thus obtained, ring-shaped OSFs were generated in six out of nine crystals. Moreover, as a result of measurement of the B concentration in a crystal having being performed on the tail-side samples by the PL method, the B concentration was  $1.46 \times 10^{12}$  to  $2.97 \times 10^{12}$  atoms/cm<sup>3</sup> (samples Nos. 1 to 9 in Table 1).

[0066] The results of the examples and the comparative example are shown in Table 1.

[Table 1]

	Sample No.	B concentration (ppba)	Presence or absence of generation of OSF
Comparative Example	1	$2.26 \times 10^{12}$ atoms/cm <sup>3</sup>	Present
	2	$1.56 \times 10^{12}$ atoms/cm <sup>3</sup>	Present
	3	$1.46 \times 10^{12}$ atoms/cm <sup>3</sup>	Present
	4	$2.52 \times 10^{12}$ atoms/cm <sup>3</sup>	Present
	5	$1.86 \times 10^{12}$ atoms/cm <sup>3</sup>	Present
	6	$1.56 \times 10^{12}$ atoms/cm <sup>3</sup>	Present
	7	$1.46 \times 10^{12}$ atoms/cm <sup>3</sup>	None
	8	$1.46 \times 10^{12}$ atoms/cm <sup>3</sup>	None
	9	$2.97 \times 10^{12}$ atoms/cm <sup>3</sup>	None
Example 1	10	$5.73 \times 10^{12}$ atoms/cm <sup>3</sup>	None
	11	$5.73 \times 10^{12}$ atoms/cm <sup>3</sup>	None
	12	$4.07 \times 10^{12}$ atoms/cm <sup>3</sup>	None
	13	$6.29 \times 10^{12}$ atoms/cm <sup>3</sup>	None
	14	$4.43 \times 10^{12}$ atoms/cm <sup>3</sup>	None
	15	$8.15 \times 10^{12}$ atoms/cm <sup>3</sup>	None
	16	$5.08 \times 10^{12}$ atoms/cm <sup>3</sup>	None
	17	$7.19 \times 10^{12}$ atoms/cm <sup>3</sup>	None
Example 2	18	$5.38 \times 10^{12}$ atoms/cm <sup>3</sup>	None
	19	$8.05 \times 10^{12}$ atoms/cm <sup>3</sup>	None
	20	$5.33 \times 10^{12}$ atoms/cm <sup>3</sup>	None
	21	$3.92 \times 10^{12}$ atoms/cm <sup>3</sup>	None
	22	$4.23 \times 10^{12}$ atoms/cm <sup>3</sup>	None
	23	$3.72 \times 10^{12}$ atoms/cm <sup>3</sup>	None
	24	$3.97 \times 10^{12}$ atoms/cm <sup>3</sup>	None
	25	$4.07 \times 10^{12}$ atoms/cm <sup>3</sup>	None
	26	$3.22 \times 10^{12}$ atoms/cm <sup>3</sup>	None
	27	$3.45 \times 10^{12}$ atoms/cm <sup>3</sup>	None

**[0067]** As indicated in Table 1, in the comparative example (samples Nos. 1 to 9), doping with B was not performed, the B concentration in the crystal was less than  $3 \times 10^{12}$  atoms/cm<sup>3</sup>, which was considered to be unavoidably mixed, and ring-shaped OSFs were generated in six out of nine crystals; on the other hand, in the examples (samples Nos. 10 to 27), as a result of performing doping with B, the B concentration in the single crystal became  $3 \times 10^{12}$  atoms/cm<sup>3</sup> or more, and ring-shaped OSFs were not generated in all of the 18 crystals.

**[0068]** As described above, with the existing method, it is clear that OSFs are generated with high frequency. On the other hand, with the method of the present invention, the generation of OSFs could be prevented, and it became clear that the method of present invention was highly effective.

**[0069]** Based on the above description, according to the method for producing an N-type silicon single crystal of the present invention, it can be said that the generation of OSFs can be prevented even when, in particular, the crystal has a large diameter of 8 inches (200 mm) or more and a high-quality FZ silicon single crystal can be produced with stability.

**[0070]** Moreover, since OSFs were not generated in all of the obtained silicon single crystals with a B concentration of  $3 \times 10^{12}$  atoms/cm<sup>3</sup> or more, it can be said that it has been proved that the generation of OSFs can be prevented more effectively when the B concentration in a crystal is  $3 \times 10^{12}$  atoms/cm<sup>3</sup> or more.

**[0071]** It is to be understood that the present invention is not limited in any way by the embodiment thereof described above. The above embodiment is merely an example, and anything that has substantially the same structure as the technical idea recited in the claims of the present invention and that offers similar workings and benefits falls within the technical scope of the present invention.

## **REFERENCES CITED IN THE DESCRIPTION**

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### **Patent documents cited in the description**

- [JPH873293B](#) **[0010]**

- [CN1865530A](#) [0011]
- [US20110030793A1](#) [0013]
- [US20010020438A1](#) [0014]
- [US20030024469A1](#) [0015]

**Non-patent literature cited in the description**

- The impact of nitrogen on the defect aggregation in silicon **W. VON AMMON et al.** JOURNAL OF CRYSTAL GROWTH ELSEVIER 20010601 vol. 226, [0012]

**Patentkrav**

- 1.** Fremgangsmåde til fremstilling af en N-type siliciummonokrystal med en diameter på 8 tommer (200 mm) eller mere med FZ-fremgangsmåden, hvor
- 5 N-type siliciummonokrystallen fremstilles ved udførelse af dotering under anvendelse af Ar-baseret PH<sub>3</sub>-gas og Ar-baseret B<sub>2</sub>H<sub>6</sub>-gas som doteringsgas, og ved at tilføre den Ar-baserede B<sub>2</sub>H<sub>6</sub>-gas på sådan en måde at en B-koncentration i N-type siliciummonokrystallen, som skal fremstilles, bliver  $3 \times 10^{12}$  atomer/cm<sup>3</sup> eller mere.
- 10
- 2.** Fremgangsmåden til fremstilling af en N-type siliciummonokrystal ifølge krav 1, hvor doteringen af den Ar-baserede PH<sub>3</sub>-gas og den Ar-baserede B<sub>2</sub>H<sub>6</sub>-gas udføres ved at blande den Ar-baserede PH<sub>3</sub>-gas og den Ar-baserede B<sub>2</sub>H<sub>6</sub>-gas og tilføre
- 15 blandingen af gasserne fra en dyse til sprøjtning af doteringsgas, hvor dysen er tilvejebragt nær smeltet smelt af et FZ-monokrystal-fremstillingsapparat, eller en doteringsgas-stråleåbning tilvejebragt under den smeltede smelt.
- 3.** Fremgangsmåden til fremstilling af en N-type siliciummonokrystal ifølge krav 1,
- 20 hvor doteringen af den Ar-baserede PH<sub>3</sub>-gas og den Ar-baserede B<sub>2</sub>H<sub>6</sub>-gas udføres ved at tilføre den Ar-baserede PH<sub>3</sub>-gas fra en dyse til sprøjtning af doteringsgas, hvor dysen er tilvejebragt nær smeltet smelt af et FZ-monokrystal-fremstillingsapparat, og ved at tilføre den Ar-baserede B<sub>2</sub>H<sub>6</sub>-gas fra en doteringsgas-stråleåbning
- 25 tilvejebragt under den smeltede smelt.

# DRAWINGS

FIG.1

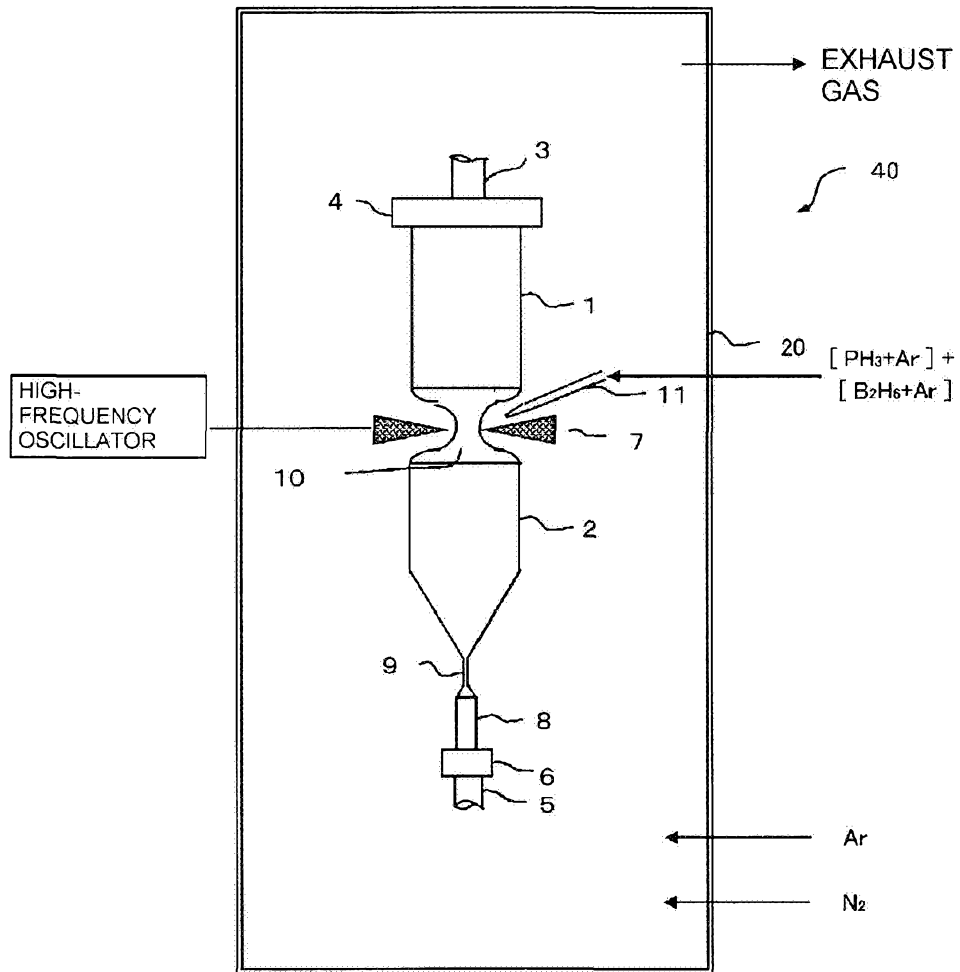


FIG.2

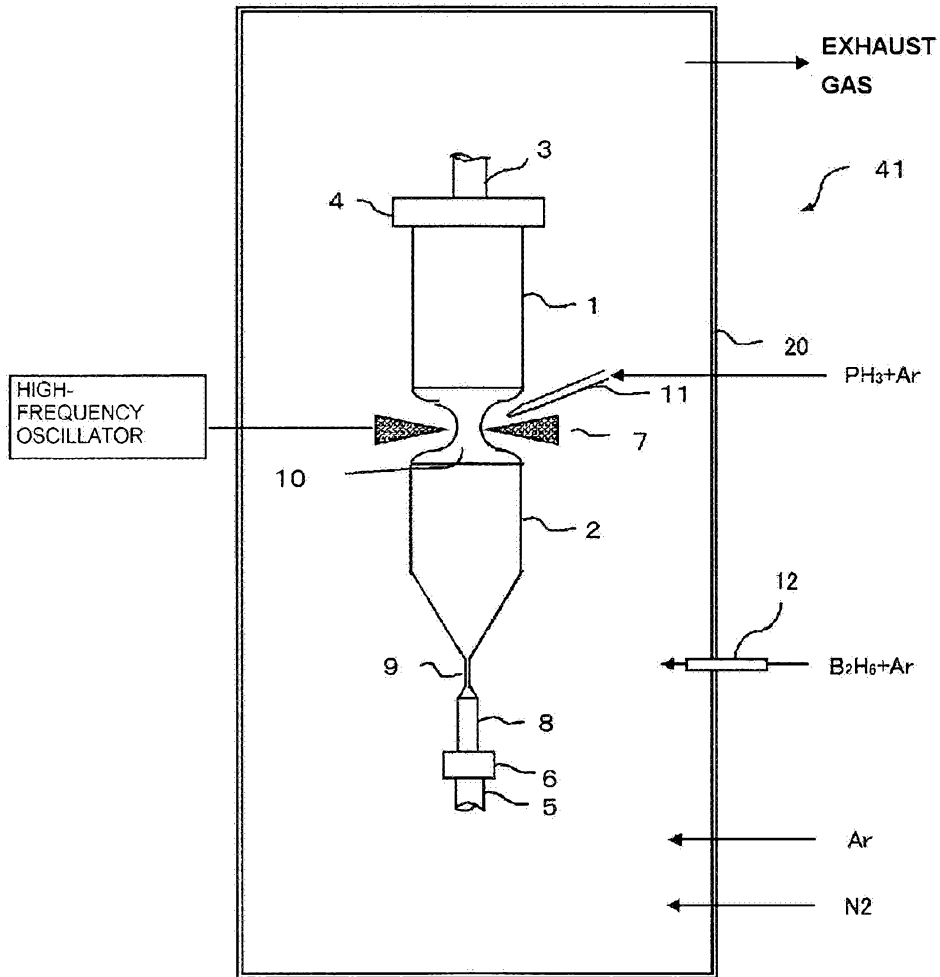


FIG.3

