Method and device for producing monocrystals

The invention relates to a method for producing silicon monocrystals having a specified defect density. The invention also relates to a device for carrying out the method.

Silicon monocrystals are produced in most practical cases by a crucible pulling method (called Czochralski method or CZ method) or by a crucible-free pulling method (called zone-melting method or FZ method). The rod-shaped monocrystals having diameters of typically 100 to 300 mm serve principally as basic material for producing "wafers", from which electronic components are in turn manufactured. On examining the monocrystals and the wafers more closely, defects of varying type and size and in varying density (number per spatial or area unit) are found which have been produced during the pulling of the monocrystal.

In connection with the present invention, mention should first be made of the flow pattern defects (hereinafter abbreviated to "FPD"). These can be made visible as etch points having wedge-shaped etching tails after 30 min of Secco etching (H. Yamagishi, I. Fusegawa, N. Fujimaki and M. Katayama, Semicond. Sci. Technol. 7 (1992) A 135). The FPD density directly influences the breakdown strength of an oxide film produced on a silicon wafer. An important criterion for assessing the breakdown strength is the so-called GOI yield ("gate oxide integrity"). At high FPD densities, the GOI yields are low. Wafers which are provided for producing electronic components ("prime wafers") should have as high GOI yields as possible because the yield of serviceable components also depends on high GOI yields. However, the GOI yield for test wafers ("monitor wafers"), which are used not to produce electronic components but only to check the component production processes, is of rather subordinate importance.

EP-504 837 A2 discloses the fact that dwell times

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

of the growing monocrystal at temperatures of over 1150°C have a favorable influence on the GOI yield.

Another class of defects includes the light point defects (abbreviated to "LPD" hereinafter), which can be detected on polished wafer surfaces using optical measuring instruments. If light point defects can be detected in high density, the wafers concerned are regarded as inferior both for use as prime wafers and for use as monitor wafers, unless the magnitude of the LPD is predominantly in a range of less than 0.12 μm. In this case, use of the wafers as monitor wafers is quite possible since the defects are not harmful because their size is below the currently standard line width of component structures. In addition, the number of said LPDs can be considerably reduced and the GIO yield increased at the same time by a special heat treatment (annealing), so that wafers treated in this way are also suitable as prime wafers.

The present invention achieves the object of improving the production of silicon monocrystals in such a way that wafers which are cut from a pulled monocrystal either exhibit a particularly high GOI yield and are therefore particularly well suited as prime wafers or have LPDs whose magnitude is predominantly in the range of less than 0.12 μm, so that use as monitor wafers and possibly also use as prime wafers is particularly applicable.

The invention relates to a method for producing a silicon monocrystal, in which the growing monocrystal is kept for a specified dwell time in a specified temperature range, wherein the range from 850 to 1100°C is chosen as temperature range and the dwell time of the growing monocrystal in the chosen temperature range is either greater than 250 min or less than 80 min.

It is particularly preferred that the range from 900 to 1050°C is chosen as temperature range and the dwell time in said temperature range is either greater than 150 min or less than 50 min.

If the dwell time of the growing monocrystal in the temperature range from 850 to 1100°C is greater than 250 min, the silicon wafers cut from the monocrystal have very low FPD densities and very high GOI yields. They are therefore very well suited as prime wafers. On the other hand, if the dwell time in said temperature range is shortened to less than 80 min, very high LPD densities are found in the wafers cut from the monocrystal. These wafers are very well suited as monitor wafers because the size of the defects is predominantly less than 0.12 µm. Use of the wafers as prime wafers is also possible, provided the number of defects is reduced by a heat treatment of the wafers at approximately 1100 to 1200°C in argon atmosphere or hydrogen atmosphere.

The setting of the dwell time can be critically influenced by the pulling speed and the thermal screening of the growing monocrystal. The higher the pulling speed is, the shorter the dwell time of the growing monocrystal in a specified temperature range becomes. The rate at which the growing monocrystal cools depends critically on the thermal screening of the monocrystal, it being particularly necessary to take into consideration the screening of a heating source, for example a crucible heating system. From the pulling of silicon monocrystals by the CZ method, heat shields are known in various designs which are used to shield the growing monocrystal thermally. The more heat-transparent the heat shield is to heat radiation and thermal conduction, the more slowly a growing section of the monocrystal cools and the longer the temperature of said section remains in a specified temperature range. The appropriate harmonization of pulling speed and thermal screening of the monocrystal to achieve the dwell time envisaged in the temperature range envisaged is facilitated by preliminary computer simulations and trials. A suitable simulation program can be developed, for example, on the basis of model calculations by Dubret et al. (Dubret et al., Int. J. Heat Mass Transfer, Vol. 33, No. 9, pages 1849 - 1871,

1990. Particular attention should be paid to the values which the heat shield has in regard to thermal conductivity and transparency to heat radiation. Known materials for heat shields are, for example, molybdenum sheet, graphite and graphite felt. Some heat shields are laminarly constructed composite bodies of such materials.

The inventors have now developed an improvement of the heat shield, in which the improved heat shield is particularly suitable for carrying out said method.

The invention also relates to a device for producing a silicon monocrystal using a heat shield which surrounds the growing monocrystal, wherein the heat shield is subdivided into at least two annular zones between a lower and an upper rim and adjacent zones differ in regard to thermal conductivity and transparency to heat radiation.

The improved heat shield is always advantageous if the temperature variation with time (the temperature history) in a specified section of the growing monocrystal is to be influenced during the pulling operation.

The invention therefore also relates to a method for producing a silicon monocrystal, wherein the cooling rate of the growing monocrystal is influenced by a heat shield which surrounds the growing monocrystal, the heat shield being subdivided into annular zones between a lower and an upper rim and adjacent zones differing in regard to thermal conduction and transparency to heat radiation.

Known heat shields are composed of homogeneous material having uniform properties in regard to thermal conduction and transparency to heat radiation. The heat shield according to the invention is subdivided into at least 2, preferably 2 to 5, annular zones. Starting from the lower rim of the heat shield, there follows a zone of the next to the upper rim of the heat shield. A particular characteristic of the zones is that two adjacent zones differ in regard to thermal conduction and

transparency to heat radiation. Thus, for example, a repeated sequence of zones with strong thermal insulation and less strong thermal insulation is possible in order to adjust the cooling rate of the growing monocrystal for a desired defect distribution and defect density at constant pulling speed. The heat shield according to the invention may be made up of annular segments which are disposed one above the other. Adjacent segments are composed of materials which differ in regard to thermal conduction and transparency to heat radiation. That two segments are connected only by means of struts so that the open gap between the segments acts as a zone with particularly high transparency to heat radiation is not ruled out. Optionally, a segment may also be actively cooled or heated by using a cooling or heating device and a control system may be provided with which the cooling efficiency or heating efficiency of the device is matched to the requirements of the desired cooling rate of the monocrystal. A heat shield according to the invention is also produced if suitable zones are provided in a known heat shield by active cooling or heating. A requirement in this connection is, however, that the cooling or heating remains limited essentially to the particular zone of the heat shield and is not immediately transmitted to adjacent zones by thermal conduction.

The heat shield has proved particularly advantageous for pulling by the CZ method, in particular if pulling is carried out at speeds of more than 0.5 mm/min. According to the findings of the inventors, the radial temperature gradient must be as high as possible on the surface of the melt around the phase boundary between monocrystal and melt so that the monocrystal grows cylindrically and does not form any bulges directed transversely to the direction of growth. With a special embodiment of the heat shield, it is possible to ensure a high radial temperature gradient and, consequently, a stable crystal growth even at pulling speeds at which the use of a known heat shield would result in an unstable

crystal growth. This embodiment is one wherein the zone at the lower rim of the heat shield, which is closest to the phase boundary between monocrystal and melt, has an emission coefficient of 0.3 to 0.9 and a thermal conductivity of 0.02 to 5 Wm^{-1} K^{-1} and therefore has special thermally insulating action.

The invention is explained in greater detail below by reference to two figures. Figure 1 shows, in a longitudinal sectional view, the diagrammatic structure of a pulling system for pulling a monocrystal by the CZ method. The invention can, however, also be used in the FZ method. Only the features essential to the understanding of the invention are shown since the basic construction of pulling systems for producing monocrystals both by the CZ method and by the FZ method has long been known from many publications.

Figure 2 relates to the results of an example described later and shows a diagram in which the density of the GOI defects is plotted as a function of the dwell time of the growing monocrystal in the temperature range from 900 to 1050°C.

The growing monocrystal 1, which is pulled from a melt 2 can be seen in Figure 1. As particular features of the device, only a heat shield 3, a cover 7 and an additional insulation 8 are shown. The monocrystal is surrounded by the heat shield 3. At its upper rim 6, the heat shield is supported by the cover 7, which divides the surrounding space of the pulling system into a lower part and an upper part. In the upper part of the pulling system, the monocrystal is thermally shielded by the heat shield 3 and optionally by the additional insulation 8. The temperature history in the cooling of the monocrystal can be influenced and also the additional insulation by the heat shield. According to the invention, the heat shield is subdivided into annular zones between the lower rim 5 and the upper rim 6, adjacent zones differing in regard to thermal conduction and transparency to heat radiation. The heat shield shown comprises five annular

segments 4a - 4e, which are disposed one above the other. Each segment also forms a zone having specified thermal conductivity and transparency to heat radiation. The materials for the segments are preferably selected from a group which comprises graphite, graphite felt, quartz, silicon, CFC, molybdenum, silver and laminated composite structures of two or more of said materials.

It is preferable that the segment at the lower rim 5 of the heat shield has special thermally insulating action so that the radial temperature gradient, characterized as "DT_{rad}" is as high as possible on the surface of the melt around the phase boundary between monocrystal and melt.

Example:

Silicon monocrystals having diameters of 150 mm to 300 mm were pulled by the CZ method and cut into wafers. During a pulling operation, the pulling speed remained almost unaltered. The dwell times of the monocrystals in the temperature range from 900 to 1050°C varied. The density of the GOI defects was examined in the wafers obtained.

The results of the examination are shown in Figure 2. Placed in front of every measured value shown is a figure which describes the diameter of the pulled monocrystal. The figures 6, 8 and 12 stand for a diameter of 150 mm, 200 mm and 300 mm. The letter (A to E) following a figure denotes a specified thermal screening of the monocrystal. Defect densities and dwell times are specified in normalized units.

It can clearly be seen that the defect density depends on the dwell time of the monocrystal in said temperature range. For a short dwell time, the defect density was very high and, consequently, the GOI yield was low. However, the size of the defects remained essentially below 0.12 μm, so that these wafers were suitable as monitor wafers and, after a heat treatment at approximately 1100°C in a hydrogen atmosphere, also very

well suited as primary wafers. The lowest defect densities and highest GOI yields were found in wafers which originated from monocrystals whose dwell time in the temperature range from 900 to 1050°C was longer than 150 min. These wafers were very well suited as prime wafers.

* C L M S *

Patent Claims:

1. A method for producing a silicon monocrystal, in which the growing monocrystal is kept for a specified dwell time in a specified temperature range, wherein the range from 850 to 1100°C is chosen as temperature range and the dwell time of the growing monocrystal in the chosen temperature range is either greater than 250 min or less than 80 min.

2. A method for producing a silicon monocrystal, wherein the cooling rate of the growing monocrystal is influenced by a heat shield which surrounds the growing monocrystal, the heat shield being subdivided into annular zones between a lower rim and an upper rim and adjacent zones differing in regard to thermal conduction and transparency to heat radiation.

3. The method as claimed in claim 2, wherein the zone at the lower rim of the heat shield has an emission coefficient of 0.3 to 0.9 and a thermal conductivity of 0.02 to 5 $Wm^{-1} K^{-1}$.

4. A device for producing a silicon monocrystal having a heat shield which surrounds the growing monocrystal, wherein the heat shield is subdivided into at least two annular zones between a lower rim and an upper rim, and adjacent zones differ in regard to thermal conductivity and transparency to heat radiation.

5. The device as claimed in claim 4, wherein the zone at the lower rim of the heat shield has an emission coefficient of 0.3 to 0.9 and a thermal conductivity of 0.02 to 5 $Wm^{-1} K^{-1}$.

6. The device as claimed in claim 4 or claim 5, wherein at least one of the zones can be cooled by a cooling device.

7. The device as claimed in claim 4 or claim 5, wherein at least one of the zones can be heated by a heating device.

8. The device as claimed in any one of claims 4 to 7, wherein the total number of zones is 2 to 5.

9. The device as claimed in any one of claims 4 to

This Sheet Has Been Replaced

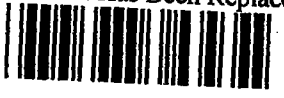


THIS SHEET HAS BEEN REPLACED



7, wherein the heat shield is manufactured from at least one material which is chosen from the group of materials comprising graphite, graphite felt, quartz, silicon, CFC, molybdenum, silver and laminated composite structures of two or more of said materials.

This Sheet Has Been Replaced



THIS SHEET HAS BEEN REPLACED

Method and device for producing monocrystals

Abstract

The invention relates to a method for producing a silicon monocrystal, in which the growing monocrystal is kept for a specified dwell time in a specified temperature range, wherein the range from 850 to 1100°C is chosen as the temperature range and the dwell time of the growing monocrystal in the chosen temperature range is either greater than 250 min or less than 80 min. The invention also relates to a device and a method, in which the cooling rate of the growing monocrystal is influenced by a heat shield which is subdivided into annular zones between a lower rim and an upper rim, adjacent zones differing in regard to thermal conduction and transparency to heat radiation.

This Sheet Has Been Replaced



THIS SHEET HAS BEEN REPLACED

Copy with English description
for information only
(CMM Patent Reproduction Services, Munich)

Fig. 1

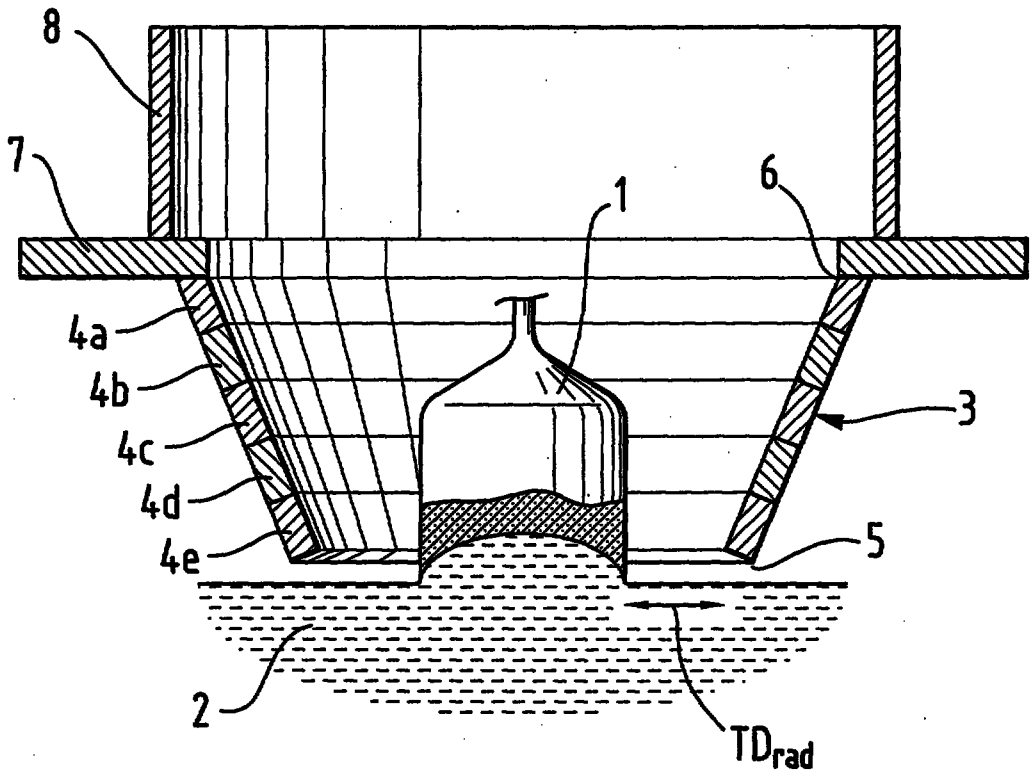
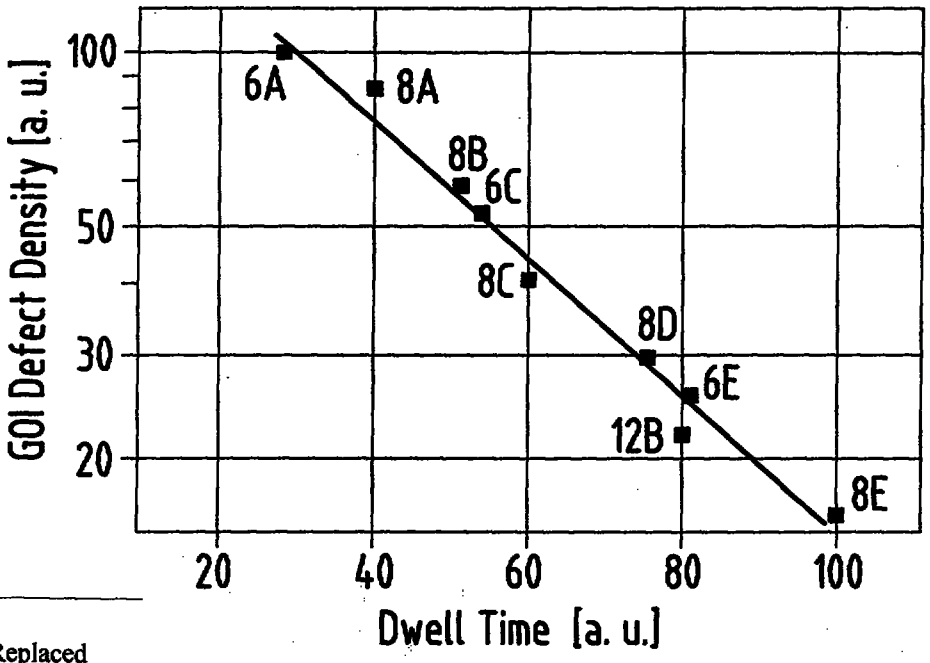


Fig. 2



This Sheet Has Been Replaced



THIS SHEET HAS BEEN REPLACED

970924-4
IPOr

REPLACEMENT SHEET
29 AUG 1997

Method and device for producing monocrystals

The invention relates to a method for producing silicon monocrystals having a specified defect density. The invention also relates to a device for carrying out the method.

Silicon monocrystals are produced in most practical cases by a crucible pulling method (called Czochralski method or CZ method) or by a crucible-free pulling method (called zone-melting method or FZ method). The rod-shaped monocrystals having diameters of typically 100 to 300 mm serve principally as basic material for producing wafers, from which electronic components are in turn manufactured. On examining the monocrystals and the wafers more closely, defects of varying type and size and in varying density (number per spatial or area unit) are found which have been produced during the pulling of the monocrystal.

In connection with the present invention, mention should first be made of the flow pattern defects (hereinafter abbreviated to "FPD"). These can be made visible as etch points having wedge-shaped etching tails after 30 min of Secco etching (H. Yamagishi, I. Fusegawa, N. Fujimaki and M. Katayama, Semicond. Sci. Technol. 7 (1992) A 135). The FPD density directly influences the breakdown strength of an oxide film produced on a silicon wafer. An important criterion for assessing the breakdown strength is the so-called GOI yield ("gate oxide integrity"). At high FPD densities, the GOI yields are low. Wafers which are provided for producing electronic components ("prime wafers") should have as high GOI yields as possible because the yield of serviceable components also depends on high GOI yields. However, the GOI yield for test wafers ("monitor wafers"), which are used not to produce electronic components but only to check the component production processes, is of rather subordinate importance.

EP-504 837 A2 discloses the fact that dwell times

REPLACEMENT SHEET
29 AUG 1997

Method and device for producing monocrystals

Abstract

The invention relates to a method for producing a silicon monocrystal, in which the growing monocrystal is kept for a specified dwell time in a specified temperature range, wherein the range from 850 to 1100°C is chosen as the temperature range and the dwell time of the growing monocrystal in the chosen temperature range is either greater than 250 min or less than 80 min. The invention also relates to a device and a method, in which the cooling rate of the growing monocrystal is influenced by a heat shield which is subdivided into annular zones between a lower rim and an upper rim, adjacent zones differing in regard to thermal conduction and transparency to heat radiation.

Figure 1

97:924-4
IPOS

Fig. 1

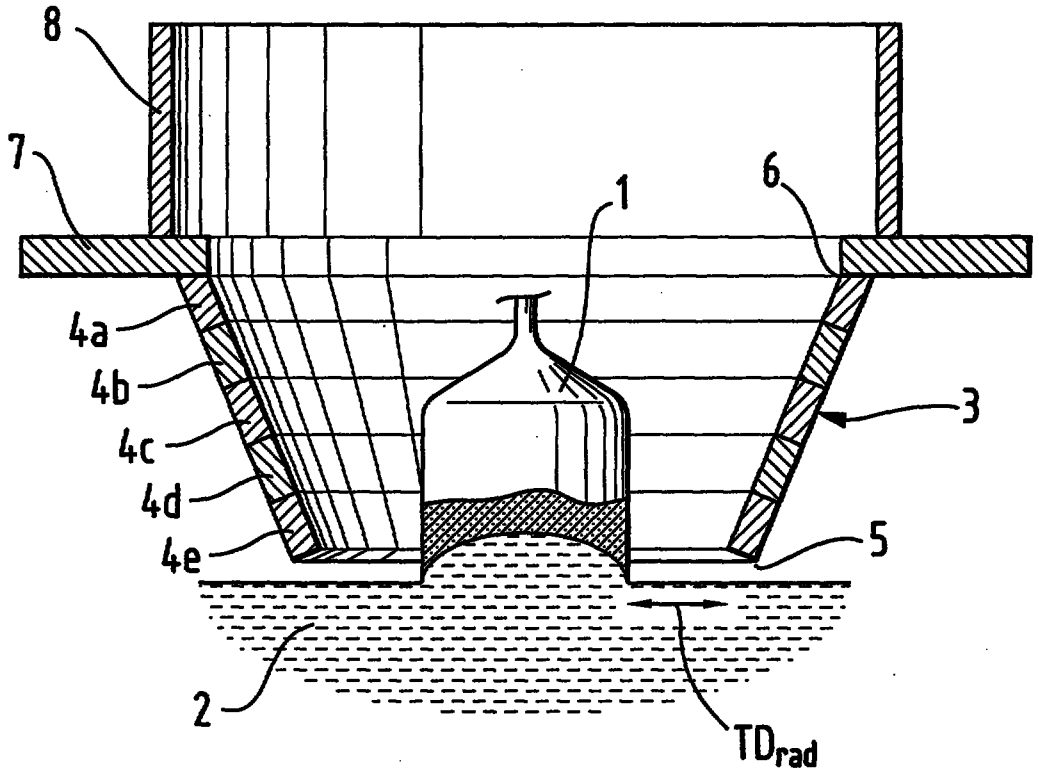
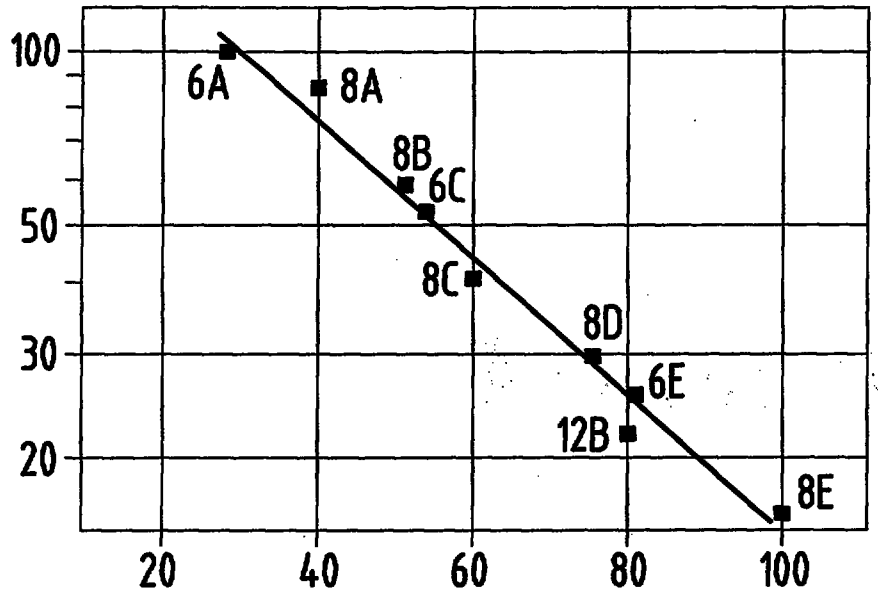


Fig. 2



REPLACEMENT SHEET
03 OCT 1997

970924-4
I PDS

* C L M S *

Patent Claims :

1. A method for producing a silicon monocrystal comprising

keeping a growing monocrystal for a dwell time within a temperature range of from 850°C to 1100°C; and

maintaining the dwell time of the growing monocrystal in said temperature range to be greater than 250 min.

2. A device for producing a silicon monocrystal, comprising

a heat shield for surrounding a growing monocrystal, said heat shield having a lower rim and an upper rim; and said heat shield being subdivided into at least two adjacent annular zones between said lower rim and said upper rim;

said adjacent annular zones differing from one another in regard to each's thermal conduction and transparency to heat radiation; and

wherein the heat shield is made from material which is selected from the group consisting of graphite, graphite felt, silicon, CFC, silver and a composite structure laminate of at least two of said materials.

3. The device as claimed in claim 2, wherein the zone at the lower rim of the heat shield has an emission coefficient of 0.3 to 0.9 and a thermal conductivity of 0.02 to 5 Wm^{-1} K^{-1}.

4. The device as claimed in any one of claims 2 to 3, wherein the total number of zones is 2 to 5.

5. A method for producing a silicon monocrystal comprising

keeping a growing monocrystal for a dwell time within a temperature range of from 850°C to 1100°C;

maintaining the dwell time of the growing monocrystal in said temperature range to be less than 80 min;

cutting wafers from the silicon monocrystal; and

annealing the wafers in an atmosphere selected from the group consisting of argon and hydrogen.

REPLACEMENT SHEET
24 DEC 1998

* C L M S *

6. A method for producing a silicon monocrystal comprising

keeping a growing monocrystal for a dwell time within a temperature range of from 850°C to 1100°C; and

maintaining the dwell time of the growing monocrystal in said temperature range to be greater than 150 min.

REPLACEMENT SHEET

24 DEC 1998