

Method of producing an epitaxially coated semiconductor wafer of monocrystalline silicon

- 5 The invention provides a method of producing an epitaxially coated semiconductor wafer from monocrystalline silicon, which is especially suitable for further processing to give electronic components such as CMOS image sensors (CISs).

Prior art / problems

- 10 In order to be suitable for the application mentioned, metallic impurities must not reach the electronic structures accommodated in the epitaxial layer.

- US 2014/0374861 A1 states that the presence of oxygen precipitates, called BMDs (bulk microdefects), in the substrate wafer on which the epitaxial layer has been
15 deposited suppresses typical component defects attributable to contamination with metallic impurities, provided that the concentration of BMDs is at least $1.0 \times 10^9 / \text{cm}^3$.

- In order to be able to provide such a comparatively high contamination of BMDs, it is frequently suggested that the single crystal that provides the substrate wafer be
20 doped with nitrogen or carbon and/or that the substrate wafer, prior to the deposition of the epitaxial layer, be subjected to a heat treatment that stabilizes nuclei from which BMDs can form at a later stage.

- Owing to the doping with nitrogen or carbon, however, surface defects can also arise
25 in the epitaxial layer, and the heat treatment of the substrate wafer constitutes an additional method step that increases manufacturing costs.

- DE 10 2014 221 421 B3 describes a method that does not require the doping with nitrogen and does not require any heat treatment prior to the deposition of the
30 epitaxial layer. A disadvantage of this method, however, is that the required BMD density of at least $1.0 \times 10^9 / \text{cm}^3$ is not attained and is not distributed uniformly, but drops toward the edge of the semiconductor wafer with an epitaxial layer.

It is an object of the present invention to provide such a method that provides a semiconductor wafer with an epitaxial layer in which it is possible to generate a BMD density that reaches at least $1.0 \times 10^9 / \text{cm}^3$, including in the edge region thereof.

- 5 The object of the invention is achieved by a method of producing an epitaxially coated semiconductor wafer from monocrystalline silicon, comprising:
the providing of a melt of silicon in a crucible;
the pulling of a single crystal of silicon from a surface of the melt with a pulling speed v by the CZ method, wherein oxygen and boron are incorporated into the single
10 crystal and the concentration of oxygen in the single crystal is not less than 6.4×10^{17} atoms/ cm^3 and not more than 8.0×10^{17} atoms/ cm^3 , and the resistivity of the single crystal is not less than $10 \text{ m}\Omega\text{cm}$ and not more than $25 \text{ m}\Omega\text{cm}$, and wherein there is no doping of the melt with nitrogen and carbon;
the applying of a CUSP magnetic field to the melt during the pulling of the single
15 crystal of silicon, surrounded by a heat shield;
the controlling of the pulling speed v and of an axial temperature gradient G at the phase boundary between the single crystal and the melt in such a way that the quotient v/G is not less than $0.13 \text{ mm}^2/^\circ\text{C min}$ and not more than $0.20 \text{ mm}^2/^\circ\text{C min}$;
the heating of the single crystal by means of a ring-shaped heater which is disposed
20 above the melt and surrounds the single crystal;
the producing of a substrate wafer from monocrystalline silicon having a polished lateral face by processing the single crystal of silicon; and
the depositing of an epitaxial layer of silicon on the polished lateral face of the substrate wafer, wherein the depositing of the epitaxial layer is the first heat treatment
25 in the course of which the substrate wafer is heated to a temperature of not less than 700°C .

- An epitaxially coated semiconductor wafer of monocrystalline silicon that has p/p+ doping and has been produced by this method is particularly suitable for the
30 production of CIS components, especially owing to the radially homogeneous BMD distribution that can be generated by means of a heat treatment beneath the epitaxial layer. The heat treatment preferably comprises the heating of the epitaxially coated semiconductor wafer first to a temperature of 780°C over a period of 3 h and then to a temperature of 1000°C over a period of 16 h. Alternatively, it is also possible to

conduct a heat treatment with a comparable thermal budget in the course of further processing of the epitaxially coated semiconductor wafer to give electronic components.

- 5 The single crystal from which the substrate wafer that is epitaxially coated in the course of the method is divided is produced by the MCZ method, wherein the single crystal is pulled using a seed crystal from a melt which is generated in a crucible and is subjected to a magnetic field. The magnetic field used in an axially symmetric magnetic field, a CUSP magnetic field. The CUSP magnetic field attains a maximum
10 field strength of preferably not less than 105 mT and not more than 116 mT, with the plane of the CUSP magnetic field having a field strength of 0 mT being preferably not less than 30 mm and not more than 80 mm, more preferably 50 mm, below the surface of the melt.
- 15 The single crystal is preferably cooled actively. The cooling rate in the temperature range from 1000°C to 800°C is preferably not less than 0.7°C/min and not more than 1°C/min.

- The distance of a lower edge of the heat shield from the surface of the melt is
20 preferably not less than 35 mm and not more than 45 mm.

- The amount of oxygen that gets into the single crystal in the course of pulling off the single crystal is controlled via the adjustment of process parameters. These process parameters especially include the strength of the CUSP magnetic field, the speed of
25 rotation of the crucible, and the pressure of the purge gas which is passed over the melt in order to remove silicon dioxide escaping from the melt from the environment of the single crystal. The speed of rotation of the crucible is preferably not less than 3.5 rpm and not more than 6.0 rpm. The pressure of the purge gas, for example of argon, hydrogen or a mixture of the two gases, is preferably not less than 2500 Pa
30 and not more than 8500 Pa.

The point defect distribution in the single crystal has a particular influence on the ability of BMDs to form later in the epitaxially coated semiconductor wafer. As is well

known, the point defect distribution depends on the value that the quotient v/G had during the pulling of the single crystal. Material factors are accordingly the ratio of pulling speed v and the axial temperature gradient G , and the phase boundary between the growing single crystal on the melt. The method according to the invention
5 requires a quotient v/G of not less than $0.13 \text{ mm}^2/\text{°C min}$ and not more than $0.20 \text{ mm}^2/\text{°C min}$. The pulling speed is preferably not less than 0.4 mm/min and not more than 0.48 mm/min .

The axial temperature gradient G in the edge region of the growing single crystal is
10 additionally influenced by the heating of the single crystal by means of a ring-shaped heater which is disposed above the melt and surrounds the single crystal. For a single crystal having a diameter of 300 mm , the power of the ring-shaped heater is preferably not less than 7 kW and not more than 13 kW .

15 The pulled single crystal has a diameter of preferably at least 200 mm , more preferably at least 300 mm , and is processed to give substrate wafers of monocrystalline silicon. The operating steps include, as well as the dividing of the single crystal into wafers, further mechanical processing steps such as the lapping and/or grinding of the lateral faces of the wafers and the rounding off the edges of the
20 wafers. The substrate wafers are preferably also chemically etched and especially chemically-mechanically polished. A substrate wafer therefore has a polished edge and at least one polished lateral face. Preferably, the polishing steps comprise the simultaneous polishing (DSP) of the front and reverse faces of the substrate wafer and the polishing (CMP) of the front face of the substrate wafer.

25 The epitaxial layer of silicon is preferably deposited on the polished front face of the substrate wafer. This step is preferably conducted in a single-wafer reactor, for example in a reactor of the Centura[®] type supplied by Applied Materials. The deposition gas preferably contains a hydrogen-containing silane, for example
30 trichlorosilane (TCS). The deposition temperature, when TCS is used, is within a temperature range of preferably not less than 1000°C and not more than 1250°C . The thickness of the epitaxial layer is preferably at least $1 \text{ }\mu\text{m}$. The depositing of the epitaxial layer is the first heat treatment in the course of which the substrate wafer is

heated to a temperature of not less than 700°C. Prior to the depositing of the epitaxial layer, there is thus no heat treatment for nucleation of the BMD seeds. The substrate wafer is also not intentionally doped with nitrogen and/or carbon.

- 5 The epitaxially coated semiconductor wafer of monocrystalline silicon thus produced, in the region of the substrate wafer, has the concentration of interstitial oxygen and the resistivity of the single crystal from which the substrate wafer originates. The concentration of oxygen is accordingly not less than 6.4×10^{17} atoms/cm³ and not more than 8.0×10^{17} atoms/cm³ (according to the standard new ASTM), and the
10 resistivity is not less than 10 mΩcm and not more than 25 mΩcm.

If the epitaxially coated semiconductor wafer of monocrystalline silicon is subjected to a standard heat treatment comprising heating to a temperature of 780°C over a period of 3 h and then to a temperature of 1000°C over a period of 16 h, or a heat treatment
15 with a comparable thermal budget, BMDs are formed beneath the epitaxial layer with a density of at least 1×10^9 / cm³, in a radially homogeneous distribution. The variation in the BMD density over the radius is less than 170%, calculated by the formula $((\text{BMDmax} - \text{BMDmin}) / \text{BMDmean}) \times 100\%$, where BMDmax, BMDmin and BMDmean denote the measured greatest, smallest and average BMD density.

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The invention is described further hereinafter with reference to drawings.

Brief description of the figures

- 25 **Fig. 1** shows features of apparatus suitable for executing the method according to the invention.

Fig. 2 shows the averaged BMD densities of epitaxially coated semiconductor layers produced in accordance with the invention after a standard heat treatment, as a
30 function of the relative axial position, depending on the relative axial position (raP) of the corresponding substrate wafers in the single crystal.

Fig. 3 shows the averaged BMD densities of five epitaxially coated semiconductor wafers produced in accordance with the invention, depending on the radial position (Pos) at which the BMD densities have been measured.

5 **List of reference numerals used**

- 1 single crystal
- 2 heat shield
- 3 melt
- 10 4 ring-shaped heater
- 5 device for cooling the single crystal
- 6 crucible
- 7 outer crucible
- 8 shaft
- 15 9 resistance heater
- 10 device for generation of a CUSP magnetic field

Detailed description of inventive working examples

Fig.1 shows the schematic diagram of the immediate environment (hot zone) of the single crystal during production thereof, with use of an apparatus suitable for performance of the method according to the invention. The growing single crystal 1 is surrounded by a heat shield 2, the lower end of which is at a short distance from the melt 3. Additionally present in the region of the lower end of the heat shield 2 is a ring-shaped heater 4, which supplies the heat to the edge of the phase boundary between the single crystal 1 and the melt 3. The ring-shaped heater 4 assists the control of the temperature gradient at the edge of the phase boundary between the growing single crystal 1 and amount 3, and is preferably also part of a control system for the diameter of the single crystal. At the level of the middle and upper region of the heat shield 2 and at a certain distance from the ring-shaped heater 4, the single crystal 1 is also surrounded by a device 5 for cooling the single crystal, preferably a water-cooled cooler. The melt 3 is present in a crucible 6 made of quartz, which is in turn held by an outer crucible 7 made of graphite. The crucibles 6, 7 and the melt 3 rest on an end of a rotatable, liftable and lowerable shaft 8. The melt 3 is supplied mainly with heat via a resistance heater 9, disposed around the outer crucible 7. A device 10 for generating

the CUSP magnetic field which is applied to the melt 3 surrounds the resistance heater 9 in turn.

Multiple single crystals of silicon were pulled in an inventive manner in a device
5 having the features shown in Fig.1 and processed further to give epitaxially coated semiconductor wafers having a diameter of 300 mm.

Fig. 2 shows the averaged BMD densities (BMD-D) of the semiconductor wafers after
a standard heat treatment depending on the relative axial position (raP) of the
10 corresponding substrate wafers in the single crystal.

Fig. 3 shows the averaged BMD densities (BMD-D) of five of the epitaxially coated
semiconductor wafers produced in accordance with the invention depending on the
radial position (Pos) at which the BMD densities have been measured.

Claims

1. Method of producing an epitaxially coated semiconductor wafer from monocrystalline silicon, comprising:

- 5 the providing of a melt of silicon in a crucible;
- the pulling of a single crystal of silicon from a surface of the melt with a pulling speed v by the CZ method, wherein oxygen and boron are incorporated into the single crystal and the concentration of oxygen in the single crystal is not less than 6.4×10^{17} atoms/cm³ and not more than 8.0×10^{17} atoms/cm³, and the resistivity of the single
- 10 crystal is not less than 10 mΩcm and not more than 25 mΩcm, and wherein there is no doping of the melt with nitrogen and carbon;
- the applying of a CUSP magnetic field to the melt during the pulling of the single crystal of silicon, surrounded by a heat shield;
- the controlling of the pulling speed v and of an axial temperature gradient G at the
- 15 phase boundary between the single crystal and the melt in such a way that the quotient v/G is not less than 0.13 mm²/°C min and not more than 0.20 mm²/°C min;
- the heating of the single crystal by means of a ring-shaped heater which is disposed above the melt and surrounds the single crystal;
- the producing of a substrate wafer from monocrystalline silicon having a polished
- 20 lateral face by processing the single crystal of silicon; and
- the depositing of an epitaxial layer of silicon on the polished lateral face of the substrate wafer, wherein the depositing of the epitaxial layer is the first heat treatment in the course of which the substrate wafer is heated to a temperature of not less than 700°C.

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2. Method according to Claim 1, characterized by the cooling of the single crystal pulled from the melt at a cooling rate within a temperature range from 1000°C to 800°C which is not less than 0.7°C/min and not more than 1°C/min.

- 30 3. Method according to Claim 1 or Claim 2, characterized in that the distance of a lower edge of the heat shield from the surface of the melt is not less than 35 mm and not more than 45 mm.

- 4. Method according to any of Claims 1 to 3, characterized in that the CUSP magnetic
- 35 field attains a maximum field strength of not less than 105 mT and not more than

116 mT, and the plane of the CUSP magnetic field with a field strength of 0 mT is not less than 30 mm and not more than 80 mm below the surface of the melt.

5 5. Method according to any of Claims 1 to 4, characterized by the rotating of the crucible at a speed of less than 3.5 rpm and not more than 6.0 rpm.

6. Method according to any of Claims 1 to 5, characterized by the pulling of single crystal in an atmosphere of purge gas, the pressure of which is not less than 2500 Pa and not more than 8500 Pa.

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7. Method according to any of Claims 1 to 6, characterized in that the single crystal has a diameter of 300 mm, and the power of the ring-shaped heater is not less than 7 kW and not more than 13 kW.