

Ring-shaped resistance heater for supplying heat to a growing single crystal

The invention relates to a ring-shaped resistance heater for supplying heat to a growing single crystal.

One method for producing single crystals is the Czochralski method. It is employed, for example, for producing single crystals composed of silicon. In accordance with this method, firstly a melt is produced in a crucible, then a seed crystal is brought into contact with the melt and, finally, a single crystal suspended from the seed crystal is caused to grow by the seed crystal being pulled upward from the surface of the melt.

It is advantageous if heat can be supplied to the growing single crystal by means of a ring-shaped resistance heater, which is also called a ring heater hereinafter. Thus, US 2004/0192015 describes a method wherein heat is supplied to the phase boundary of the growing single crystal by means of a ring heater in order to homogenize the axial temperature gradients at the phase boundary along the radius of the single crystal. The aim of the measure is to influence the formation of intrinsic point defects to the effect that the defect properties of the grown single crystal are as uniform as possible in a radial direction.

US6,132,507 mentions that a ring heater can also be used to reduce fluctuations of the diameter of the single crystal and the growth rate.

The inventors of the present invention have ascertained that the use of a ring heater for supplying heat to a growing single crystal poses difficulties if, at the same time, a strong external magnetic field is built up in order to influence the flow in the melt. An

electromagnetic interaction between the external magnetic field and the magnetic field generated by the ring heater occurs in such a case. The Lorentz force acting on the ring heater can alter the position of the ring heater, damage the ring heater or even destroy the latter.

US7,335,864 B2 describes the fact that the inherent magnetic field of a resistance heater can be reduced by a heating coil being wound in a bifilar fashion, such that the electric current flows in opposite directions through the partial turns of the heating coil.

However, despite the use of a ring heater modified in this way, the difficulties mentioned cannot be eliminated satisfactorily because the interaction between the magnetic fields remains, albeit in weakened form.

Therefore, the object of the present invention is to provide a ring-shaped resistance heater for supplying heat to a growing single crystal which has the advantages of the ring heater described in US 2004/0192015 A1 without having the disadvantages thereof during use in the presence of a strong external magnetic field.

The object is achieved by means of a ring-shaped resistance heater for supplying heat to a growing single crystal, comprising
an upper and a lower ring, which are electrically conductively connected by means of a loop adjacent to a ring gap of the lower ring, such that the flow direction of electric current which is conducted through the rings is opposite in the rings;
connecting elements which hold the upper and lower rings together at a distance; and

current leads for conducting electric current through the upper and lower rings.

The ring heater of the present invention comprises two ring-shaped partial coils arranged one above the other, said partial coils also being designated hereafter as upper and lower rings and being connected by means of a loop to form an integral component. The flow direction of electric current that flows through the partial coils reverses when passing through the loop. The ring heater thus has the structure and properties of a coil wound in bifilar fashion.

Preferably, the upper and lower rings and the current leads substantially consist of carbon, for example carbon fiber reinforced carbon (CFC) or graphite. Graphite is particularly preferred, in particular a graphite type having the lowest possible resistivity, the highest possible flexural strength and the highest possible thermal conductivity. In order that the area of the cross section of the rings can be as small as possible, the resistivity should preferably be not more than $11 \mu\Omega\text{m}$. The flexural strength should preferably be not less than 50 MPa, and the thermal conductivity should preferably be not less than 120 W/mK. The high thermal conductivity prevents a formation of overheated locations ("hot spots") that accelerate the wear of the ring heater.

Connecting elements hold the upper and lower rings together and at a specific distance from one another. They thereby compensate for electromagnetic forces which act on the rings, and prevent, in particular, the rings from being displaced relative to one another under the influence of a magnetic field acting on the melt. The distance between the rings is preferably not less than 2 mm and not more than 150 mm. A distance smaller than 2 mm is not preferred, owing to the risk

of electrical flashovers occurring, and a distance greater than 150 mm is likewise not preferred either, because then the advantages of the bifilar structure of the ring heater are no longer adequately manifested. The connecting elements can be embodied in such a way that, at the connecting locations, the upper ring is electrically insulated from the lower ring. Equally, the connecting elements can be embodied in such a way that they conduct away part of the electric current flowing through the rings. Said part should in each case be not more than 5% of the total electrical power. A configuration of this type can be achieved, for example, by the upper and lower rings being screwed to each other directly by means of a screw composed of carbon fiber reinforced carbon (CFC).

The upper ring and the lower ring are carried by current leads fixed to the upper and lower rings, respectively. It is preferred to connect the current leads to one another in an electrically insulated manner and to secure them in this way against a force which compresses them or pulls them apart and which is brought about by a strong external magnetic field. The stronger external magnetic field is, for example, a horizontal magnetic field or a cusp magnetic field that is impressed on the melt.

It is preferred to embody the upper and lower rings in a widened fashion in the region of the fixing locations of the current leads. This strengthens the mechanical stability of the rings in this region and reduces the current density, such that local overheating is avoided.

The ring heater is used to supply heat to a growing single crystal, preferably for the purpose of influencing the radial profile of the axial temperature gradient at the phase boundary of the growing single crystal and for regulating the diameter of the growing

single crystal. The single crystal is preferably a single crystal composed of silicon having a diameter of not less than 300 mm, particularly preferably having a diameter of 300 mm or 450 mm.

The invention is explained in greater detail below with reference to figures. The figures show particularly preferred configuration features of the ring heater.

Figure 1 shows the ring heater without connecting elements and without current leads in a perspective illustration.

Figure 2 shows the ring heater in accordance with figure 1 with the connecting elements and the current leads in a perspective illustration.

Figure 3 is a sectional illustration through the ring heater in the region of the current leads.

Figure 4 is a sectional illustration through the current leads in the region of the clamping connection.

The ring heater in accordance with figure 1 comprises an upper ring 1 and a lower ring 2, wherein both rings are interrupted by ring gaps, which are arranged in an offset manner. The ring gap 3 of the lower ring is adjacent to a loop 4, which connects the upper ring 1 to the lower ring 2. The ring gap 5 of the upper ring is preferably wide enough in order that there is space for fixing the current lead of the lower ring. Preferably, there is space for a base 6, which increases the thickness of the lower ring in the region of the base, such that the fixing locations of the current leads are situated at the same level.

Owing to the offset arrangement of the ring gaps, an end 7 of the upper ring and an end 8 of the lower ring overlap in the region between the base 6 and the ring

gap 3 of the lower ring. The edges of the upper ring and of the lower ring, in particular the edges at the outer circumference and at the inner circumference of the rings, are rounded. Rounding the edges reduces the risk of electrical flashovers occurring.

On the end sides of the rings, holes 9 are distributed over the circumference, said holes leading congruously in the thickness direction through the upper and lower rings. The holes are preferably distributed centrally and at identical distances on the end sides in order to avoid asymmetries. They are preferably situated, in particular, also at locations at which the rings are subjected to particularly high mechanical loading. Where the end 7 of the upper ring and the end 8 of the lower ring overlap, holes 9 lying radially alongside one another are present instead of centrally arranged holes. Holes for fixing the rings to current leads are situated on the end side of the base 6 and on the end side of a further end 10 of the upper ring 1.

It is preferred to widen the rings in the region of their ends and in the region of the base 6 in order to increase the mechanical stability and reduce the current densities there.

Figure 2 reveals that the holes serve for the most part for accommodating connecting elements 18, which hold the upper ring and the lower ring, to be precise at a specific distance and such that they are electrically insulated from one another, or in such a way that the connecting elements form a high-impedance line between the rings. The hole on the end side at the end 10 of the upper ring and the hole on the end side of the base 6 serve for fixing the upper ring 1 to a current lead 11 of the upper ring and for fixing the lower ring 2 to a current lead 12 of the lower ring. The base 6 increases the thickness of the lower ring 2 preferably

in such a way that the rings are fixed to the current leads at locations at the same level.

In the case of the ring heater illustrated in figure 2, the current lead 11 of the upper ring and the current lead 12 of the lower ring are connected to one another by means of a clamping connection 19 at at least one location. The clamping connection 19 secures the current leads against an electromagnetic force of a strong external magnetic field, said force compressing said current leads. In addition or instead of the clamping connection 19, it is possible to provide one or a plurality of connections of the current leads which secure the current leads against an electromagnetic force of a strong external magnetic field, said force forcing apart said leads.

In accordance with figure 3, the connecting elements 18 preferably comprise in each case a ring-shaped spacer 13, hollow cylinders 14, a screw 15 and a screw nut 16. The diameter of the hollow cylinders 14 is preferably widened at one end by a collar 17. The ring-shaped spacer 13 is arranged between the rings. The hollow cylinders are inserted through the holes and line the latter. The screw 15, which extends through the hollow cylinders 14 and the spacer 13, is screwed at its end to the screw nut 16. The screw nut is preferably closed by a blind hole.

During assembly, firstly the ring-shaped spacer 13 is pushed between the upper ring 1 and the lower ring 2 and then a hollow cylinder 14 is inserted through the hole in the upper ring into the spacer. A further hollow cylinder 14 is then inserted through the lower ring 2 into the spacer and the arrangement is screwed together with the screw 15 and the screw nut 16. In order to save structural height, the collars 17 of the hollow cylinders 14 are countersunk into the end side

of the upper ring 1 and into the opposite side of the end side of the lower ring 2.

The hollow cylinders 14 and the ring-shaped spacer 13 consist of a temperature-resistant and electrically insulating material, preferably of boron nitride.

The screw 15 and the screw nut 16 consist of a temperature-resistant material that is resistant to tensile, shear and torsional loading, preferably of carbon fiber reinforced carbon (CFC).

The ring-shaped spacer 13 absorbs compressive forces that compress the rings under the action of a strong external magnetic field, and the screw 15 absorbs tensile forces that pull the rings apart under the action of a strong external magnetic field.

The current lead 11 of the upper ring 1 conducts a comparatively high current density into the upper ring. The fixing means for fixing the upper ring 1 to the current lead 11 should therefore be temperature-resistant and have a comparatively low resistivity. It is therefore preferred to fix the upper ring to the current lead 11 using a screw 20 composed of graphite. Furthermore, it is advantageous, in order to enlarge the contact area, to form the screw 20 as a countersunk screw.

The current lead 12 of the lower ring 2 carries a large part of the weight of the ring heater. The fixing means for fixing the lower ring 2 to the current lead 12 should therefore be temperature-resistant and have a comparatively high mechanical stability. It is therefore preferred to fix the lower ring to the current lead 12 using a screw 21 composed of carbon fiber reinforced carbon (CFC).

In accordance with figure 4, the clamping connection 19 comprises a pin 22, which is arranged transversally with respect to the longitudinal direction of the current lead 11 of the upper ring and the current lead 12 of the lower ring and over which electrically insulating mounts 23 are slipped. The mounts 23 are placed with washers 24 in holes in the current leads and are held in position by a screw 25. The pin 22 and the washers 24 preferably consist of carbon fiber reinforced carbon (CFC), and the mounts 23 preferably consist of boron nitride.

Example:

The mechanical stability of a ring heater comprising the features of the illustrations in figures 1 to 4 was tested under conditions such as occur in the method described in US 2004/0192015 A1. With comparable performance, a lower susceptibility of the ring heater to wear and faults was found in comparison with the ring heater described in said document. Furthermore, the ring heater described in said document was able to be replaced by the ring heater according to the invention without this necessitating structural alterations on the apparatus for producing single crystals.

Patent Claims

1. A ring-shaped resistance heater for supplying heat to a growing single crystal, comprising an upper and a lower ring, which are electrically conductively connected by means of a loop adjacent to a ring gap of the lower ring, such that the flow direction of electric current which is conducted through the rings is opposite in the rings; connecting elements which hold the upper and lower rings together at a distance; and current leads for conducting electric current through the upper and lower rings.

2. The resistance heater as claimed in claim 1, wherein the upper and lower rings and the current leads substantially consist of carbon.

3. The resistance heater as claimed in claim 1 or claim 2, wherein edges of the upper and lower rings are rounded.

4. The resistance heater as claimed in any of claims 1 to 3, wherein the connecting elements each comprise a ring-shaped spacer, hollow cylinders, a screw and a screw nut, wherein the ring-shaped spacer is arranged between the rings, the hollow cylinders line holes through the rings in the thickness direction, and the screw is screwed at its end to the screw nut and extends through the hollow cylinders and the spacer.

5. The resistance heater as claimed in claim 4, wherein collars of the hollow cylinders are countersunk in side areas of the upper and lower rings.

6. The resistance heater as claimed in any of claims 1 to 5, wherein the upper and lower rings are held together by connecting elements at a location

which lies alongside the loop and alongside the current lead of the lower ring.

7. The resistance heater as claimed in any of claims 1 to 6, wherein the upper ring is fixed to the current lead of the upper ring by means of a screw composed of graphite.

8. The resistance heater as claimed in any of claims 1 to 7, wherein the lower ring is fixed to the current lead of the lower ring by means of a screw composed of CFC.

9. The resistance heater as claimed in any of claims 1 to 8, characterized by a clamping connection that secures the current leads against an electromagnetic force compressing them.

10. The resistance heater as claimed in claim 9, wherein the clamping connection comprises a pin, which is arranged transversally with respect to the longitudinal direction of the current leads and over which electrically insulating mounts are slipped, and a screw, which holds the mounts and the pin in position.