# Method for Pulling a Silicon Single Crystal

The invention relates to a method for pulling a silicon single crystal from a melt which is contained in a crucible. In such a method a seed crystal is immersed into the melt and raised, material of the melt being crystallized on the seed crystal to form a single crystal. After a stabilization phase, first a neck section is pulled and later a conical section is pulled, the diameter of the growing single crystal being widened to a setpoint diameter during pulling of the conical section. The melt not only contains silicon, but conventionally also one or more dopants which are intended to be incorporated in the lattice of the single crystal in order to determine the electrical conductivity of the single crystal. The melt furthermore contains oxygen, which is dissolved from the crucible material and partially incorporated by the single crystal. The oxygen contained in the single crystal has advantageous and disadvantageous effects. Precipitates containing oxygen, i.e. so-called BMDs (bulk micro-defects), act as internal getters which can bind metallic impurities and thereby prevent them from interfering with the functions of electronic components. High oxygen concentrations, on the other hand, also promote the formation of detrimental stacking faults, so-called OSFs (oxidation-induced stacking faults). It is therefore desirable to control the oxygen concentration in the single crystal, and likewise the concentration of dopants, so that they do not depart from a narrowly specified concentration range at least in the region of the single crystal's cylindrical section which is used for the production of semiconductor wafers, has the setpoint diameter and is adjacent to the conical section.

The oxygen concentration in the single crystal can be influenced in various ways, for example by controlling the gas pressure in the reactor, by controlling the speed with which

inert gas is fed through the reactor, by controlling the distance between the melt surface and the lower end of a heat shield enclosing the single crystal, by controlling the rotation speed of the single crystal and the crucible, and by controlling the strength of a magnetic field applied to the melt. Despite the use of such control measures, there are problems in obtaining the oxygen concentration in the specified concentration range from the start, i.e. already at the start of the cylindrical section of the single crystal. If the semiconductor wafers obtained from the start of the cylindrical section of the single crystal do not have the oxygen concentration specified by the customer, this leads to a yield loss which is commensurately more serious when the diameter of the single crystal is larger and when its cylindrical section is shorter.

It is an object of the present invention to provide a method, with the aid of which such yield losses can be substantially reduced.

This object is achieved by a method for pulling a silicon single crystal from a melt which is contained in a crucible, comprising
immersion of a seed crystal into the melt;
crystallization of the single crystal on the seed crystal by raising the seed crystal from the melt with a crystal pull speed;
widening the diameter of the single crystal to a setpoint diameter in a conical section, comprising
control of the crystal pull speed in such a way as to induce a curvature inversion of a growth front of the single crystal in the conical section.

Studies by the Inventor have revealed that particular attention must be paid to the phase during which the conical section of

the single crystal is being pulled, so as not to incur a yield loss due to absence of the specified oxygen concentration at the start of the cylindrical section of the single crystal. It is necessary to ensure that the crystal pull speed, with which the single crystal growing on the seed crystal is pulled, is controlled in such a way that a curvature inversion of the single crystal is achieved in the conical section.

Preferably, the crystal pull speed is first reduced and subsequently increased during the phase of pulling the conical section of the single crystal.

When pulling the conical section, it is particularly preferable to reduce the crystal pull speed from an initial speed to a lower crystal pull speed which is at least 40%, preferably at least 60% less than the initial speed, and to increase it again from the lower crystal pull speed to a final speed. The final speed will be the crystal pull speed until the setpoint diameter is reached. The initial speed is also preferably higher than the final speed.

It is furthermore preferable for the seed crystal not to be raised with the lower crystal pull speed until the diameter of the conical section has reached at least 50% of the setpoint diameter.

The invention will be explained in more detail below with the aid of figures.

Figs 1 and 2 show a single crystal which has been pulled according to the invention, in the region of the conical section.
Fig. 3 shows the positions of the angles $\alpha$ and $\beta$ in the single crystal according to Fig. 1 and Fig. 2.

Fig. 4 shows the profile of the crystal pull speed while pulling the conical section, with reference to the example of a silicon single crystal having a setpoint diameter of 200 mm.

When a single crystal is cut axially, segregation strips of dopants and oxygen reveal the profile of the growth front. The segregation strips are due to temperature variations in the melt, owing to which the concentrations of the dopants and oxygen also vary to a greater or lesser extent in the radial direction of the single crystal.

Reducing and increasing the crystal pull speed, as described above, leads to an inversion of the curvature of the growth front in the conical section. Initially, the growth front is curved concavely as seen looking toward the seed crystal. According to the invention, the change to a convex curvature of the growth front still takes place in the conical section of the single crystal owing to the control of the crystal pull rate.

Fig. 1 represents the seed crystal 3, the conical section 2 and the start of the cylindrical section 1 of a single crystal, which has been pulled according to the invention. Between the seed crystal and the conical section, there is a neck section. The diameter of the conical section increases to the setpoint diameter, which is reached at the transition to the cylindrical section. The growth front shown by the curved segregation strips 5 is shaped in such a way that the segregation strips' curvature existing in the cylindrical section is inverted in the conical section. There is no inversion of curvature in the cylindrical section.

The single crystal according to Fig. 2 differs from that in Fig 1 by a second section 4 above the conical section 2. Such thickening is generally required when pulling a single crystal

which is so heavy that the seed crystal or the neck section could tear off owing to the weight load, if the single crystal is not supported by a holding system on the thickened part.

For carrying out the method, it is advantageous that the axial length of the conical section 2 should be longer than would be necessary in order to widen the diameter of the conical section to the setpoint diameter. The conical section therefore preferably has an apex angle $\alpha$ of not less than 60° and not more than 90°, particularly preferably not more than 80°. And the external angle $\beta$ at the transition from the conical section 2 to the cylindrical section 1 is preferably not less than 5° and not more than 25°. The positions of the angles are represented in Fig. 3.

The typical axial length of the conical section is preferably from 160 to 220 mm for a single crystal having a nominal setpoint diameter of 200 mm, and preferably from 240 to 340 mm for a single crystal having a nominal setpoint diameter of 300 mm. In the case of single crystals having a nominal setpoint diameter of more than 300 mm, the axial length of the conical section will be correspondingly longer.

Example:

A silicon single crystal having a nominal setpoint diameter of 200 mm was pulled according to the invention. The profile of the crystal pull speed expressed in terms of the initial speed, i.e. V(rel), in the region of the conical section is shown in Fig. 4. The relative diameter of the conical section in relation to the setpoint diameter, i.e. D(rel), is plotted as the abscissa.

For comparison, another single crystal was pulled with the same nominal diameter but with a virtually constant crystal pull speed while pulling the conical section. In this single crystal, the region at the start of the cylindrical section did not comply with the predetermined specification in respect of the oxygen concentration. There was no such yield loss in the case of the single crystal pulled according to Fig. 4.

**Patent Claims**

1. A method for pulling a silicon single crystal from a melt which is contained in a crucible, comprising
immersion of a seed crystal into the melt;
crystallization of the single crystal on the seed crystal by raising the seed crystal from the melt with a crystal pull speed;
widening the diameter of the single crystal to a setpoint diameter in a conical section, comprising
control of the crystal pull speed in such a way as to induce a curvature inversion of a growth front of the single crystal in the conical section.

2. The method as claimed in claim 1, comprising
reduction of the crystal pull speed from an initial speed to a lower crystal pull speed which is at least 40% less than the initial speed, and increase of the crystal pull speed from the lower crystal pull speed to a final speed, with which the seed crystal is raised until the setpoint diameter is reached.

3. The method as claimed in claim 2, characterized in that the final speed is less than the initial speed.

4. The method as claimed in claim 2 or claim 3, characterized in that the seed crystal is not raised with the lower crystal pull speed until the diameter of the conical section has reached at least 50% of the setpoint diameter.

5. The method as claimed in one of claims 1 to 4, characterized in that an apex angle $\alpha$ of not less than 60° and not less than 90° is imparted to the conical section.

6. The method as claimed in one of claims 1 to 5, characterized in that the external angle $\beta$ at the transition from the conical

section to the cylindrical section is not less than 5° and not more than 25°.

7. A silicon single crystal producible by a method as claimed in one of claims 1 to 6.