FLOATING ZONE MELTING METHOD FOR SEMICONDUCTOR RODS

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My invention relates to a method and apparatus for the crucible-free, floating zone melting of crystalline semiconductor rods.

This method is employed, for example, in the production of hyperpure monocrystalline rods of silicon or other semiconductor substances or for pulling semiconductor cores of small cross section. The rod-shaped semiconductor material is preferably mounted vertically in holding means within a vacuum chamber. A coil heated by high-frequency alternating current is moved along the rod axis, the rod being thereby melted throughout a narrow cross-sectional zone in which this manner can be passed through the rod, repeatedly if desired, in one and the same direction.

In order to initiate the zone-melting operation the semiconductor rod must first be preheated, because the slight conductance of the already extremely pure semiconductor material is not sufficient for inductive heating when the rod is cold. For this purpose, it has been proposed to use a closed ring of tungsten or molybdenum sheet material for the like disposed around the semiconductor rod, at one end thereof. Such a ring is inductively heated by the above-mentioned heater coil and transmits the heat by radiation to the rod.

Instead of said ring, a spring, for example of molybdenum, may be placed upon the semiconductor rod at one end thereof, to serve not only for clamping the rod fast in the holder but also to preheat the rod end by radiation and heat conductance when the spring is subjected to inductive heating by the said coil.

The above described methods employed for preheating the semiconductor rod, in floating zone melting, have the disadvantage of requiring a relatively long preheating period. Furthermore, the mounting of the required auxiliary means for heat transfer is difficult and also requires much time.

It is an object of my invention to eliminate these shortcomings. To this end, and in accordance with a feature of my invention, I provide one end of the semiconductor rod, which was preferably produced by precipitation from a gaseous compound, with a comparatively small body of hyperpure carbon, for example spectral carbon or hyperpure graphite. The latter is fused together with the semiconductor material, or is otherwise joined with or molded into the rod end. This terminal body of the rod has a much better electric conductance than the semiconductor material. When the semiconductor rod is mounted in the zone-melting device the carbon body merged therewith serves to provide an inductively heatable, good-conducting zone which is capable of initiating the zone-melting operation proper.

The invention is predicated upon the following observations and considerations.


2. In such processes, a thin rod-shaped silicon core upon which further amounts of silicon are to be precipitated, by heat decomposition or reduction of the gaseous silicon compound, is in most cases not inserted directly into the cooled holder that serves as conductor for the supply of electric current passing through the rod. Such direct connection of the core would not be satisfactory because the rod remains relatively cool in the vicinity of the current-supply electrodes, due to good heat dissipation by these electrodes. This would cause electric resistance to the heating current to be too great.

In such precipitation processes it is therefore advantageous to insert a carbon or graphite piece between the current supplying holder or electrode and the thin rod-shaped silicon core. Carbon is a good electric conductor and has a high melting point, but its conductance for heat is relatively poor. If the carbon is used in hyperpure condition, there is no danger of contaminating the semiconductor material. During the precipitation process, producing an increase in thickness of the silicon core, the rod end adjacent to the said intermediate piece of carbon is heated up to the temperature of the silicon core. Silicon is therefore also precipitated upon the said rod end, and tightly envelopes this end. The resulting fusion of the carbon or graphite piece with the semiconductor material then permits an especially simplified method and means for the desired rapid heating-up of the silicon rod during the subsequent crucible-free zone melting.

The silicon rod, with the adherent piece of carbon is then mounted in the zone-melting equipment, and the carbon piece is first heated inductively to a sufficiently high temperature to place the adjacent silicon in incandescence. The adjacent silicon thus becomes electrically good conducting, and hence capable of being heated inductively. The heating power is at first kept so small that the silicon does not melt, and while supplying such heating power the good conducting zone is first moved to the other end of the rod. At that locality the heating power supplied to the inductive heater is increased and the glazing zone of silicon is melted. While this takes place, the silicon rod is preferably joined by melting to a seed piece of the same silicon material which is clamped fast in the adjacent holder. The clamped piece may consist of a monocrystalline seed, so that the semiconductor rod is converted into a monocrystal by the subsequent zone-melting operation.

The invention will be further explained with reference to a preferred embodiment of an apparatus employed for its performance, as illustrated in the accompanying drawings. The illustration is fragmentary but will be readily understood by persons skilled in the art or persons having knowledge of the many publications now available on zone melting of semiconductors. The evacuated housing usually employed is not shown, and also the lower holder for the silicon rod and the customary mechanism for relative longitudinal displacement of the induction heating coil and said rod. The drawing illustrates the upper portion of an elongated thickened cylindrical semiconductor rod 2 produced by precipitation of silicon from a gaseous silicon compound onto an original thin core rod 3 of the same silicon material. The thin silicon rod 3 was originally inserted into the axial center bore of an intermediate cylindrical piece of high-purity carbon 4, preparatory to said precipitation. During the said preceding precipitation process the silicon rod 3 was thickened, thus producing thick rod 2, and causing the dotted end of the carbon piece 4 to become solidly embedded in the end of the thick rod 2.

To carry out the zone melting, the carbon piece 4 is thus attached to the rod 2 is inserted into a cylindrical rod holder 5, the inner diameter of the latter being sufficiently large to accommodate the intermediate carbon
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3. In a method of crucible-free floating zone melting of a silicon rod, in which the rod is supported in a vertical position, and a transversely extending molten zone is formed in the rod by inductive heating; the melt being supported by adherence to the adjacent solid rod portions, and in which said zone is caused to move lengthwise of the rod, the improvement in said zone melting comprising previously precipitating silicon upon a silicon rod and about an end portion of a piece of hyperpure carbon attached to said silicon rod, so that one end of said carbon end portion becomes embedded in precipitated silicon, attaching the exposed end of said carbon end portion to a support and supporting the silicon rod in the zone melting in vertical position, and initiating the zone melting process by inductive heating of said carbon end portion sufficient to heat the adjacent end portion of the silicon rod to a temperature causing a zone thereof to become electroconductive and heatable by electric induction but not to melt it, and displacing the said zone away from the carbon and thereafter raising the temperature of said zone to melting temperature.

I claim:

1. In a method of crucible-free floating zone melting of a silicon rod, in which the rod is supported in a vertical position, and a transversely extending molten zone is formed in the rod by inductive heating, the melt being supported by adherence to the adjacent solid rod portions, and in which said zone is caused to move lengthwise of the rod, the improvement in said zone melting comprising previously precipitating silicon upon a silicon rod and about an end portion of a piece of hyperpure carbon attached to said silicon rod, so that one end of said carbon end portion becomes embedded in precipitated silicon, attaching the exposed end of said carbon end portion to a support and supporting the silicon rod in the zone melting in vertical position, and initiating the zone melting process by inductive heating of said carbon end portion sufficient to heat the adjacent end portion of the silicon rod to a temperature causing a zone thereof to become electroconductive and heatable by electric induction but not to melt it, and displacing the said zone away from the carbon and thereafter raising the temperature of said zone to melting temperature.

2. In a method of crucible-free floating zone melting of a silicon rod, in which the rod is supported in a vertical position, and a transversely extending molten zone is formed in the rod by inductive heating, the melt being supported by adherence to the adjacent solid rod portions, and in which said zone is caused to move lengthwise of the rod, the improvement in said zone melting comprising first precipitating the silicon upon a silicon rod and about an end portion of a piece of hyperpure carbon attached to said silicon rod by passing an electric current through the said silicon rod and attached piece of carbon to heat the rod, and passing a gaseous compound of silicon in contact with the heated rod to decompose the compound to silicon and one end of the carbon end portion becomes embedded in the precipitated silicon, thereafter attaching the exposed end of said carbon end portion to a support to support the silicon rod in a zone-melting apparatus in a vertical position, initiating the zone-melting process by inductive heating of the carbon end portion sufficient to heat the adjacent end portion of the silicon rod to a temperature causing a zone thereof to become electroconductive and heatable by electric induction but not sufficient to melt the silicon rod, and displacing the zone away from the carbon end portion and thereafter raising the temperature of said zone to melting temperature.

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