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T. RUMMEL ET AL

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PRODUCING ROD-SHAPED SEMICONDUCTOR CRYSTALS

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Fig.1

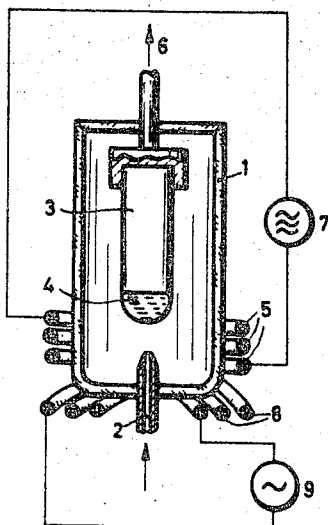


Fig.2

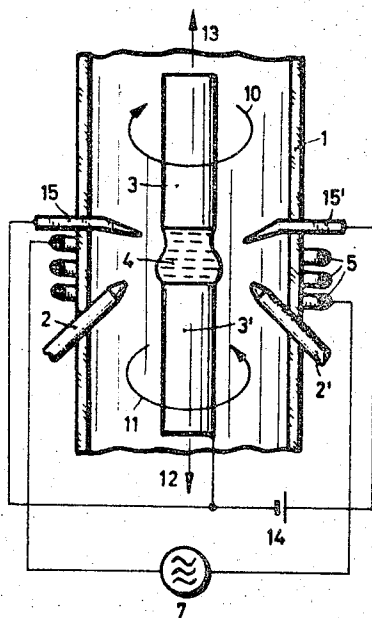
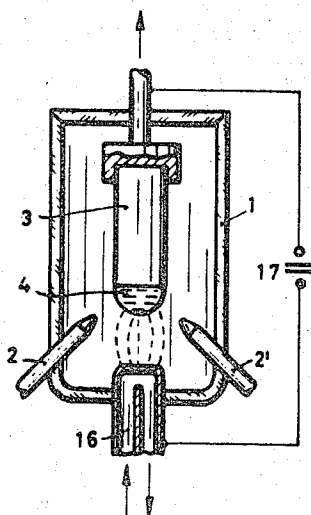


Fig.3



INVENTORS
Theodor Rummel
Heinrich Kniepkamp
Reiner Emeis
BY *Slie & Slie* ATTYS.

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PRODUCING ROD-SHAPED SEMICONDUCTOR CRYSTALS

Theodor Rummel, Munich, Heinrich Kniepkamp, Karlsruhe, and Reiner Emeis, Pretzfeld, Upper Franconia, Germany, assignors to Siemens & Halske Aktiengesellschaft, Berlin and Munich, Germany, a German corporation

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7 Claims. (Cl. 75-10)

This invention is concerned with producing rod-shaped semiconductor crystals from a gaseous phase containing the corresponding semiconductor substance, the present disclosure being a continuation-in-part of copending application Serial No. 510,493, filed May 23, 1955, now patent No. 2,964,396, dated December 13, 1960, owned by the assignee also named in the present case.

In accordance with a previously known method, the desired semiconductor material is produced by decomposition, in an electric gas discharge, of a gaseous compound which contains the corresponding semiconductor substance and which is intermixed preferably with purified hydrogen gas as a reducing agent, the material being deposited or precipitated on the electrodes provided for the gas discharge and caused to crystallize thereon.

It has also been proposed to employ the above indicated prior method for producing semiconductor rods. An electric arc discharge is for this purpose effected in a reaction gas containing the desired semiconductor substance, such discharge causing separation of the elementary semiconductor substance from the reaction gas. Underneath the area of the arc discharge is disposed a carrier or seed crystal made of the corresponding semiconductor substance in the shape of a short crystal, which catches the finely distributed semiconductor material produced by the gas discharge. The upper end of the carrier crystal is thereby melted, the hot molten part preferentially receiving the separated semiconductor material. The carrier crystal is gradually drawn downwardly, away from the area of the arc discharge. The lower part of the molten area on which the separated material is precipitated is thus cooled, causing continuous crystallization thereof and thereby effecting gradual growth of the rod-shaped semiconductor body. The speed of downward withdrawal of the growing rod-shaped semiconductor body is adjusted to the rate of separation of the material from the gaseous phase, so that the size of the molten area and its position with respect to the gas discharge zone remain as constant as possible.

Instead of utilizing a gas discharge, purely thermal decomposition or reaction may be employed for separating the semiconductor material on a seed crystal made of the same material. Localization of the separation is in such case likewise possible, provided that only part of the surface of the carrier seed is caused to melt, since the formation of the liberated semiconductor material starts and is primarily effected at the hottest portions of the carrier. In accordance with a prior method, a rod-shaped semiconductor crystal is melted at its upper end, and the corresponding melt is contacted with a reaction gas containing the semiconductor substance. The hot surface of the melt, acting as a catalyzer, favors the decomposition or reduction of the reaction gas, whereby the semiconductor substance is separated predominantly on the surface of the melt and precipitated thereon. A semiconductor rod of desired length can be produced by gradually withdrawing it from the range of the heat source which produces the melt, the melt thereby substantially retaining its relative position with respect to the heat source.

The prior methods provide for the separation of semi-

conductor substance at a molten zone at the upper end of a rod-shaped carrier crystal, to which the semiconductor substance is supplied in finely divided and especially in atomic condition, thus continuously giving off material for progressive cooling or solidification on the solid crystal carrier. The advantage of arranging the molten area at the upper end of the seed crystal resides in the fact that the melt rests upon a solid support which secures it in relatively high degree against dropping off. However, the interface between the melt and the solid crystal body extends as a rule not along a plane area but is upwardly arched, since the cooling is primarily effected by heat conduction over the solid crystal body while the heating is effected by radiation from the outside. When it is intended to work instead of with a thin molten skin, with a relatively substantial amount of molten material, which is desirable in the interest of improved crystallization, there will appear the drawback that the melt is poorly localized in its position with respect to the crystal rod, such melt constantly assuming a changed position at the tip of the seed crystal. The reason for this situation is that the melt is in the known methods relatively well secured against dropping off, but the position thereof with respect to the solid crystal carrier corresponds to a maximum of potential energy or at best to a condition of indifferent equilibrium. The disadvantage resides in the fact that the position of the melt is changed even responsive to slight disturbances, for example, such as are caused by gas flow or by the motion imparted to the crystal carrier, resulting necessarily in irregular diameter of the drawn body. The rodlike bodies are accordingly of irregular diameter and poor crystal quality, resulting in the further processing thereof to produce semiconductor devices, in great waste of costly semiconductor material. The present invention recognizes that the above indicated disadvantages can be avoided in relatively simple manner by arranging the melt, on which the semiconductor substance is to be precipitated from the gas phase, not at the upper end but at the lower end of the carrier which is made of the same material.

The present invention is accordingly concerned with a method of producing rod-shaped semiconductor crystals, comprising causing a reaction gas which contains the respective semiconductor substance or components thereof to interact with a melt carried by a solid crystal body made of the corresponding semiconductor substance, said melt receiving the substances liberated from the reaction gas by decomposition and forming the desired semiconductor material, and thereby effecting continuous growth of the solid crystal by crystallizing the substance precipitated thereon. In accordance with the invention, the melt which is to be utilized is produced by melting the crystal body at the lower end thereof, such melt depending from the crystal body in the fashion of a drop on which liberated material is precipitated by the action of an energy source, the crystal body being withdrawn upwardly at a speed adjusted to the rate at which material is precipitated, thereby withdrawing the solid crystal body from the range of action of the energy source while maintaining the size of the melt substantially constant.

The advantages which will be presently described more in detail and which have to do with utilizing a melt in the form of a downwardly depending drop, will be secured by the provision of means for additionally supporting such melt drop. The support can be effected, for example, pneumatically or by the action of an electromagnetic field, and in the latter case, if there is provided an electromagnetic energy source, by the action of such source. The molten drop may also be supported, without foregoing the advantages flowing therefrom, by means of a crystal body disposed therebelow, the molten drop

resting thereby in the form of a molten zone extending between the two vertically coextensive solid crystal bodies.

A downwardly depending molten drop would at first appear to be a relatively unstable structure which would be easily excited to execute resonance oscillations favoring dropping off, and would be in this respect inferior to a melt disposed at the upper end of the carrier; however, the downwardly depending molten drop has the considerable advantage that it always assumes the lowermost position on the seed crystal. This is due to the fact that the melt corresponds in this position to a condition of least potential energy. Accordingly, the position of the melt on the carrier will remain invariable in the interplay between melting action and crystallization action, since the melt, after decay of a disturbance, will automatically assume its lowermost position at the seed crystal. When the size of the molten drop is held constant, by adjustment of the speed of crystallization to the speed of semiconductor precipitation or separation from the reaction gas, which is easily effected, the size of the interface surface with the solid seed crystal will likewise remain constant in the course of operation.

The use of a downwardly depending drop-shaped melt at the lower end of the seed crystal must therefore necessarily result in uniform rods growing in straight manner. Even upon using at the start of the operation an irregularly shaped seed crystal as a carrier, the cross-section of the rod produced will quickly stabilize to a constant value, since the downwardly depending molten drop which is held at a constant volume leads necessarily to uniformity of a crystallization front which might have been irregular at the start of the process.

The precipitation or separation of the semiconductor substance at the hottest point in the reaction vessel, which is represented by the downwardly depending molten drop, is at any rate secured, since the surface of the hot melt as catalyzer in the liberation of the semiconductor substance from the reaction gas. The uniformity of the growth of a rod is assured to a high degree by the invention, since no noticeable distortion can be caused by the crystallization on the solidified but still hot rod incident to the withdrawal thereof.

However, if the melt is produced at the upper end of the seed crystal, as in the previously known methods, its position, while affording greater security against dropping off, will correspond to a maximum of the potential energy and therewith to an unstable equilibrium condition. While a case in which the adhesion is opposed to the force of gravity can never occur, whereby the acute danger of dropping off is largely avoided, the position of the melt on the seed crystal is nevertheless by no means invariable, as already explained before, but depends to a high degree upon chance. The size and position of the recrystallization front is accordingly subjected to considerably greater fluctuations than in the case of a downwardly depending drop, and the production of uniformly grown rods is consequently extraordinarily difficult in connection with the previously known methods.

As an additional disadvantage of the prior method may be mentioned the fact that it is very difficult to produce with the use thereof mono crystal rods. It must be considered in this connection that the size of the melt and therewith its temperature cannot be maintained as desired above the melting point of the corresponding semiconductor and, accordingly, it may easily happen that islands of solidified semiconductor material are formed on the surface of the melt due to cooling. This possibility is above all present in the neighborhood of the crystallization plane. These islands have as is known the tendency to sink downwardly and they can thus directly reach the crystallization plane and be built therein if such plane is at the deepest point of the melt. The building-in of these islands into the crystallization plane usually results in a polycrystalline degeneration of a previously present monocrystalline growth. It will be realized that the meth-

od proposed by the present invention is considerably better for producing mono crystals than the prior method, when it is considered that the use of a melt depending downwardly from the crystal body in the form of a drop forms a crystallization plane which is on top while the crystallization plane in the case of a melt provided at the upper end of a crystal body is situated at the bottom.

The foregoing and further objects and features of the invention will appear in the course of the description which is rendered below with reference to the accompanying drawing showing embodiments thereof.

The danger that the melt drops off is naturally greater in the method according to the present invention than in the prior methods. The use of a large amount of molten material is on the other hand required in the interest of good crystallization. It is in view of these aspects desirable that means be provided for increasing the mechanical stability of the melt without producing a contamination thereof. A simple way of satisfying this requirement resides in supporting the melt pneumatically by employing for this function the stream of reaction gas flowing into the apparatus. This can be effected as shown in FIG. 1, by blowing the reaction gas discharged from a nozzle against the downwardly depending molten drop so as to support it. The same function can of course be fulfilled by an inert protective gas.

Another possibility of increasing the stability of the melt resides in supporting the corresponding molten drop by means of the action of an electromagnetic field. As is known, an electromagnetic field can induce eddy currents in a conductive or in a semiconductive material, such eddy currents imparting to the material a magnetic moment. However, to a body having a magnetic moment is imparted a force, in a non-homogeneous or an electromagnetic field, which endeavors to pull the body either into a region of higher field strength or to crowd it from the region of higher field strength. The induced magnetic moment is, in the case of a non-homogeneous field, in accordance with the known rule supplied by Lenz, so oriented that it attempts to crowd the body out of the region of higher field strength. When the electromagnetic field affecting the body increases in the direction of the force of gravity, the field will tend to move the body in opposite direction. The force of the field with respect to the solid or fluid body depends upon the amount of the magnetic moment induced in the body and upon the magnitude of the gradient of the electromagnetic field. It can accordingly be made very great by an appropriately high field gradient in the direction of the force of gravity as well as by a sufficiently high amplitude and/or frequency of the alternating field. The levitation, imparted to a conductive body in such field, stops as soon as the body assumes a position in the field in which the force thereof balances the weight of the body.

Such a field is supplied by a short coil which is traversed by alternating current, the axis of the coil coinciding with the axis of the crystal carrier rod, with the molten drop situated somewhat above the symmetry plane of the coil, in some situation even somewhat above the upper margin of the coil, the coil field being in such a case oriented radially symmetrical to the axis of the carrier and the molten drop adhering to the lower end thereof, and moreover diverging upwardly at any point of the molten drop. It follows, therefore, that an upwardly directed and at the same time inwardly oriented supporting force will be operative with respect to all parts of the melt adhering in drop shape to the carrier. The dimensioning of the field strength as well as of the field gradient are a matter of experience and therefore must be determined experimentally, depending especially upon the size of the molten drop. The endeavor should be to place the meridian lines of the crystallized rod an approximately obtuse angle at the border between the solid and the fluid phase. The condition is still more favorable, in individual cases, for

example, in the processing of silicon, when the drop extends somewhat (about 10 percent) beyond the peripheral lines which delimit the crystallized material.

A third possibility for supporting the downwardly depending drop-like melt resides in the provision of a further crystal body similar to the carrier crystal and disposed thereunder for supporting the melt from below, such melt accordingly appearing as a molten zone between the two vertically coaxially arranged solid crystal bodies. These crystal bodies are drawn apart at a speed corresponding to the rate of growth of material at the melt, thus withdrawing them from the range of action of the energy source which produces the melt. The operation can be effected by using the arrangement shown in FIG. 2.

The advantages obtained from a downwardly depending molten drop are, upon use of the second crystal body for supporting it, preserved at least with respect to the portion of the rod extending upwardly from the melt. Moreover, as compared with a melt produced at the upper end of a seed crystal, the position of the contacting plane with the lower crystal body is considerably stabilized. This particular embodiment of the invention permits especially quick execution of the operation, involving drawing apart of the two crystal bodies according to the rate at which material is separated at the melt, since crystallization is effected at the upper as well as at the lower crystal bodies. The molten zone can be advantageously produced by melting a portion of a vertically extending rod-like semiconductor crystal body along a zone of limited length.

Various known means can be additionally employed in realizing the present invention. Thus, axial rotation of the rod or of the parts of the rod which carry the molten zone, will benefit the uniformity of the heating of the melt, thereby improving the properties of the crystal to be produced. In the case of round rods, the melt can be maintained in rotation by the use of an electric rotary field. The material of the melt is for this purpose permeated by a magnetic field which is produced, for example, by two magnet poles which are oppositely disposed alongside the melt but out of engagement therewith. The magnet field will become a rotary field responsive to rotation of the magnet poles about the axis of the melt, such magnet field inducing a current into the molten material. The rule supplied by Lenz, as a direct consequence of Faraday's induction law, requires, that the induction action, effected in the molten material by the rotation of the magnetic field, is subjected to local alteration, whereby the material of the melt is brought into a condition of rotation in the direction of rotation of the magnetic field. Another and easier possibility for producing the rotating field resides in utilizing a three-phase current. Such current is conducted to a coil system, in a manner known from three-phase motors, the melt functioning as the "rotor." The coils are so oriented with respect to the melt, that the magnetic lines of force permeate the melt in a direction extending perpendicular to the axis thereof, that is, horizontally.

The melt may be produced in various manner, for example, by radiation, atomic recombination energy or by electron or ion bombardment, respectively. Heating with high frequency is particularly advantageous and easily applied, the lower end of the rod being thereby concentrically surrounded by an induction coil which is supplied with alternating current, especially high frequency current, and being thus inductively heated. As already mentioned, this results in the advantage of simultaneously effecting an electromagnetic support for the melt by the action of the field of the induction coil, as soon as the melt is positioned above the median plane of the coil, such position being automatically assumed by the upward withdrawal of the solid crystal body, away from the range of heating. The seed crystal is in the case of highly pure semiconductor material usually extremely high ohmic, and it will therefore be of advantage to provide for a preheat-

ing of the crystal body upon start of the induction operation.

The choice of reaction gas to be employed will depend upon the kind of semiconductor rod which is to be produced. In the case of silicon rods to be produced, the materials to be considered aside from SiCl_4 , include higher silicon halides such as siliconhexachloride or siliconoctachloride as well as halogenated silanes such as siliconchloroform or corresponding higher homologs. In the case of germanium rods to be produced, there will be employed corresponding or appropriate germanium compounds. In order to facilitate separation of the semiconductor substance, hydrogen may be intermixed with the reaction gas, the hydrogen acting as a reducing agent.

In the method according to the invention, the separation of the silicon or other semiconductor material is effected predominantly on the surface of the melt. In addition thereto, and especially when using silane, there may occur spurious silicon production in the free gas space, which may be effected in some situation by the temperature field of the melt, although such spurious separation would be very much less as compared with the separation at the melt. In order to assure that silicon which is thus spuriously produced will reach the melt, gas streams, especially streams of the reaction gas may be directed against the melt or electrical means may be employed for this purpose. It is proposed to use for this purpose above all the so-called electric blast, an electric stream in the reaction space, which is produced, for example, by means of points or knife edges disposed opposite the melt which is grounded, such points or knife edges being charged with high voltage. The electric blast is a phenomenon which is well known in the electrostatic field. Such phenomenon is based upon the fact that a relatively very high field strength will obtain in the vicinity of edges or points of electrically charged bodies even in the presence of relatively low voltages. However, since the gas surrounding such body loses in the presence of high field strength its insulation property, due to ionization, thus becoming conductive, a discharge will occur at such edges or points. This discharge imparts to the atoms or molecules of the gas a mechanical motion directed away from the points or edges, such motion being referred to as electric blast. In the present case, there are provided two or more electrodes made of a metal, for example, tungsten, which is difficult to melt, such electrodes being provided with points extending in the direction of the melt and the crystal body carrying it, and a direct voltage of a few thousand volts is applied thereto, such voltage being however too low to effect a visible gas discharge. An electric blast will thus be produced in the reaction gas, which is directed toward the melt, thereby blowing the semiconductor material separated in the free gas space thereagainst.

In the arrangement for realizing the invention, as illustrated in FIG. 1, the seed crystal 3 is, for example, a rod-shaped highly pure silicon body which is disposed vertically in a quartz tube 1, to the lower end of which is fused a tubular nozzle 2, such nozzle serving as an inlet for the reaction gas, for example, SiCl_4 and H_2 . An induction coil 5 supplied with high frequency current from the source 7, which surrounds the lower end of the seed crystal rod 3, serves for producing the molten drop 4 at the lower end thereof. The arrangement of the gas inlet 2 underneath the molten drop 4, with the gas blowing thereagainst provides a pneumatic support for the drop and supply thereto of fresh reaction gas for direct contact with the melt, the gas giving off to the melt the major part of the silicon contained therein. The gas streaming upwardly from the surface of the melt is relatively lean so far as semiconductor material is concerned, and the possibility of separation on the solidified but as yet hot rod portion is thus greatly reduced.

The silicon separated at the surface of the molten drop 4 is taken up thereby and would accordingly effect continuous increase of the size thereof. The seed crystal 3 is

however continuously upwardly withdrawn in the direction of the arrow 6, with a speed such that the upper portion of the fluid drop is cooled off and solidifies upon leaving the induction field of the coil 5. The drawing speed and the reaction rate are mutually adjusted so that amounts of material of the drop 4 are crystallized on the solid rod 3 which correspond to the amounts separated from the reaction gas. The size of the molten drop and therewith the size of the crystallization plane remain accordingly constant. In order to adjust the speed of crystallization to the drawing speed, cooling means may be provided for accelerating the speed at which the material solidifies. However, in the case of silicon, this will not be necessary. The reaction vessel as well as the gas supply conduits may be suitably cooled so as to prevent excessive heating thereof and therewith separation thereon of the semiconductor material.

The symmetry plane of the induction coil is positioned somewhat below the molten drop. The drop is accordingly positioned within a range of the electromagnetic field possessing a gradient which effects a force operating in a direction opposite to that of the force of gravity, thereby supporting the drop electromagnetically. The dimensioning of the supporting force is a matter of experience and is increased by increasing the coil current. It is, however, advisable to effect the support of the drop independent of the heating source. This can be effected electromagnetically in the following manner:

An induction coil which is traversed by current produces in known manner a magnetic field with the lines of force diverging at the ends upon leaving the coil. The magnetic field accordingly possesses a noticeable field gradient which effects a translating force with respect to a body having a magnetic moment. If the windings of the induction coil surround the extended axis of the crystal member 3 circularly, with the coil windings being disposed along planes extending approximately perpendicularly to the vertical axis of the crystal member, the gradient of the field at the upper end will be in the direction of the force of gravity, and the gradient at the lower end of the coil will be in a direction opposite to that of the force of gravity. The melt is due to the induction effect traversed by eddy currents, therefore having a magnetic moment the direction of which is, in accordance with the Lenz rule, so oriented that the melt receives a force opposed to the field gradient, and it will be clear, therefore, that a force will act on the molten drop which is opposed to the force of gravity when the drop is situated within the range of the upwardly diverging magnetic lines of force. This will be assuredly the case when the windings of the induction coil surround the crystal 3 concentrically and when the drop is situated somewhat above the coil. The heating coil acts in such a case also as a supporting coil.

However, it is also possible to provide below the heating coil an auxiliary coil 8, operating particularly as a supporting coil, which is traversed by a low frequency current from a source 9. The heating is not particularly increased by the action of the auxiliary field, owing to the low frequency, but the supporting force is considerably increased.

The embodiment according to FIG. 1 may be realized by initially mounting in the reaction vessel 1 a cylindrical body 3 of monocrystalline silicon, about 5 centimeters long and 20 millimeters thick, after first cleaning such body with fluoric acid and drying it. The silicon crystal body 3 may also be subjected to thorough cleaning by means of etching. The reaction vessel 1, thus provided with the silicon crystal 3, is thereupon relieved of any residual moisture by conducting therethrough a stream of hydrogen. The induction coil 5 is thereafter placed in position so that its windings are situated concentrically about the extended axis of the lower end of the crystal 3 or better somewhat below the lower end thereof. High frequency energy is then supplied to the induction coil, the

strength of the coil current being increased until the lower end is melted to form the drop depending therefrom. The use of preheating, for example, by means of an infrared beam (not shown), directed against the lower end of the crystal 3, which is to be melted, or the use, for this purpose, of a radiation produced by another device, for example, illumination, will contribute toward considerably accelerating the melting operation even in the case of high ohmic semiconductor material.

The energy of the high frequency coil is increased from initially low values until the lower end of the crystal 3 is molten to form the drop depending from a crystal part which remains in solid state. The size of the drop is ascertained by experience and numerical values that would be valid for all cases cannot be given. The drop shall however be of a size such that its profile forms with the profile of the solid crystal portion an angle as extended as possible or, as will be better in many cases, for example, in the case of silicon, that the profile of the drop extends somewhat beyond the solid crystal. In the event that this is impossible owing to the surface tension of the molten material, the drop must be supported additionally. The melting is suitably effected in hydrogen gas.

The melting can be easily observed through a dark colored glass, since the molten material distinguishes optically from the solid material, and no difficulties will therefore be experienced in imparting to the drop a size such as indicated above. The appearance of instability is clearly recognized by a constriction starting to form with respect to the profile of the drop, and such condition can be counteracted and cancelled out by appropriate regulation of the heating of the drop. The danger of the dropping off of the molten drop can thus be easily prevented by careful work. The effect of supporting measures, for example, by electromagnetic support of the drop can likewise be clearly observed.

The reaction gas, for example, siliconchloroform intermixed with hydrogen is admitted into the reaction vessel as soon as the drop is of the desired size and the energy source which produces it adjusted so as to provide for substantially constant drop size. The supply of the reaction gas is in FIG. 1 effected through the nozzle 2 which is disposed underneath the drop 4, the purified reaction gas blowing against the drop in a uniform stream. The reaction gas decomposes at the hot surface of the drop, thereby separating pure silicon which is taken up by the drop, the lean spent gases moving upwardly for discharge. The amount of separated material grows with the growth of the drop surface and the drop temperature (which generally must not be considerably increased above the melting point of the material involved), and further with the amount of the silicon-containing compound in the reaction gas which contacts the drop in a time unit. The amount of the separation also depends upon the kind of the compound and can be calculated in accordance with known rules governing thermodynamics. Accordingly, the increase in the size of the drop, in a unit of time, effected by the separation of the material, can be easily determined by calculation.

However, it will generally suffice to rely upon visual observation and to start withdrawing the solid crystal body as soon as the drop begins to grow noticeably due to the separation thereon of the silicon, thus also obtaining in simple manner based upon observation, the withdrawal speed and the progressive cooling connected therewith. The withdrawal speed is so adjusted that it is proportional to the speed of material separation or precipitation thereof, which is recognized by observing that the drop size remains constant during the progress of the separation. Fluctuations in the size of the drop are in simple manner equalized or compensated by constantly effected increase or decrease of the drawing speed or by increase or decrease of the supply of reaction gas, respectively.

In the example shown in FIG. 2, the melt is in the form of a fluid zone 4 which extends between two solid highly pure silicon rods 3 and 3'. The melt may be produced, for example, by melting a median zone of a vertically positioned silicon rod. The molten zone must be such as to completely separate the solid portions of the rod so that they can be drawn apart to produce the benefits of the downwardly depending molten drop. The reaction gas enters into the vessel 1 through two oppositely disposed inlet conduits 2, 2'. The rods 3, 3', are drawn apart in the directions indicated respectively by arrows 12 and 13, in accordance with the rate of separation, and are at the same time rotated in the directions indicated by the arrows 10 and 11. It is in some situation possible to impart motion only to the upper rod, the lower rod functioning merely as a mechanical support for the molten zone 4. Instead of rotating one or both parts of the rod, the molten zone 4 may be rotated, for example, by means of a rotating field which permeates the molten zone. These and similar measures, for example, use of vibration for agitating the molten zone, can in some circumstances be advantageously applied.

FIG. 2 also shows means for producing an electric blast directed against the melt. The melt 4 is for this purpose connected, over one of the crystal members, in the illustrated case over the crystal member 3', with one terminal of an appropriate high voltage direct current source 14, such source being also connected to electrodes such as 15, 15', each of which is provided with a pointed end facing in the direction of the melt.

In the embodiment illustrated in FIG. 3, the melt 4 is produced by a gas discharge extending from the lower end of the crystal body 3 to a hollow cooled counter electrode 16, the gas discharge being effected by a voltage source 17. As a result of the cooling of the hollow counter electrode, for example, by means of a cooling gas or liquid flowing therethrough, the temperature at the surface of the electrode will not exceed the decomposition temperature of the reaction gas, and a noticeable separation or precipitation of semiconductor material will not be affected on such electrode. This result is also obtained if the counter electrode is circuited as anode and the crystal body as cathode of a direct current discharge. Suitable cooling can also be applied to other parts of the apparatus at which separation or precipitation of semiconductor material is not desired.

The invention may obviously be employed not only in the production of silicon or germanium semiconductor elements but can also be successfully applied in the production of mixed semiconductor bodies consisting of elements of the third and fifth groups of the periodic system of elements. It is of course necessary that the reaction gas contains, in the required proportions, the components of the semiconductor to be produced, which are to be given off from the gas phase at the surface of a melt which depends in the fashion of a drop from a solid crystal body made of the corresponding mixed semiconductor material. Doping substances can likewise be employed to affect the melt for building into the semiconductor rod in accordance with a desired scheme, for the purpose of producing homogeneously doped semiconductor rods and also rods with zones of different conduction type. The solid crystal bodies may also consist of a crystalline material which serves in known manner for determining a monocrystalline structure in the material which is being solidified from the molten drop.

Changes may be made within the scope and spirit of the appended claims which define what is believed to be new and desired to have protected by Letters Patent.

We claim:

1. A method of producing rod-shaped semiconductor crystals, comprising the steps of disposing in a suitable reaction vessel a solid rod-shaped body made of the semiconductor substance which is to be produced so as to extend vertically therein, applying an energy source to effect melting a portion of said rod so as to form at the lower end thereof a melt which depends downwardly therefrom in the manner of a drop, conducting to said melt a reaction gas which contains components of the semiconductor substance to be produced so as to effect decomposition of said gas and consequently separation therefrom of said semiconductor substance, said separated semiconductor substance precipitating on said melt, and moving said rod upwardly at a speed adjusted to the rate of precipitation of semiconductor substance on said melt, whereby the solidified portion of the rod, on which material from the melt crystallizes to effect growth of the rod, is removed from the range of action of the energy source to maintain the size of said melt substantially constant.

2. A method according to claim 1, comprising supporting said melt pneumatically.

3. A method according to claim 1, comprising supporting said melt by the action of an electromagnetic field.

4. A method according to claim 1, comprising transporting to said melt semiconductor particles produced in the free gas space by the application of an electric blast.

5. A method according to claim 1, comprising preheating the portion of said semiconductor rod which is to form the melt by high frequency induction.

6. A method according to claim 1, wherein said energy source is a gas discharge.

7. A method according to claim 1, comprising supporting said melt by the action of a further solid rod-shaped semiconductor body extending downwardly therefrom.

References Cited by the Examiner

UNITED STATES PATENTS

2,692,839	10/1954	Christensen et al.	148—1.5
2,907,642	10/1959	Rummel	148—1.6 X
2,964,396	12/1960	Rummel et al.	75—10
2,993,762	7/1961	Sterling et al.	148—1.6 X
3,098,741	7/1963	Enk et al.	75—10

FOREIGN PATENTS

525,102	1/1954	Belgium.
S 42,294	9/1956	Germany.

OTHER REFERENCES

Keck et al.: Review of Sci. Instr., vol. 25, No. 3, March 1954, pp. 298, 299.

DAVID L. RECK, *Primary Examiner*.

MAURICE A. BRINDISI, WINSTON A. DOUGLAS,
Examiners.