

Nov. 12, 1968

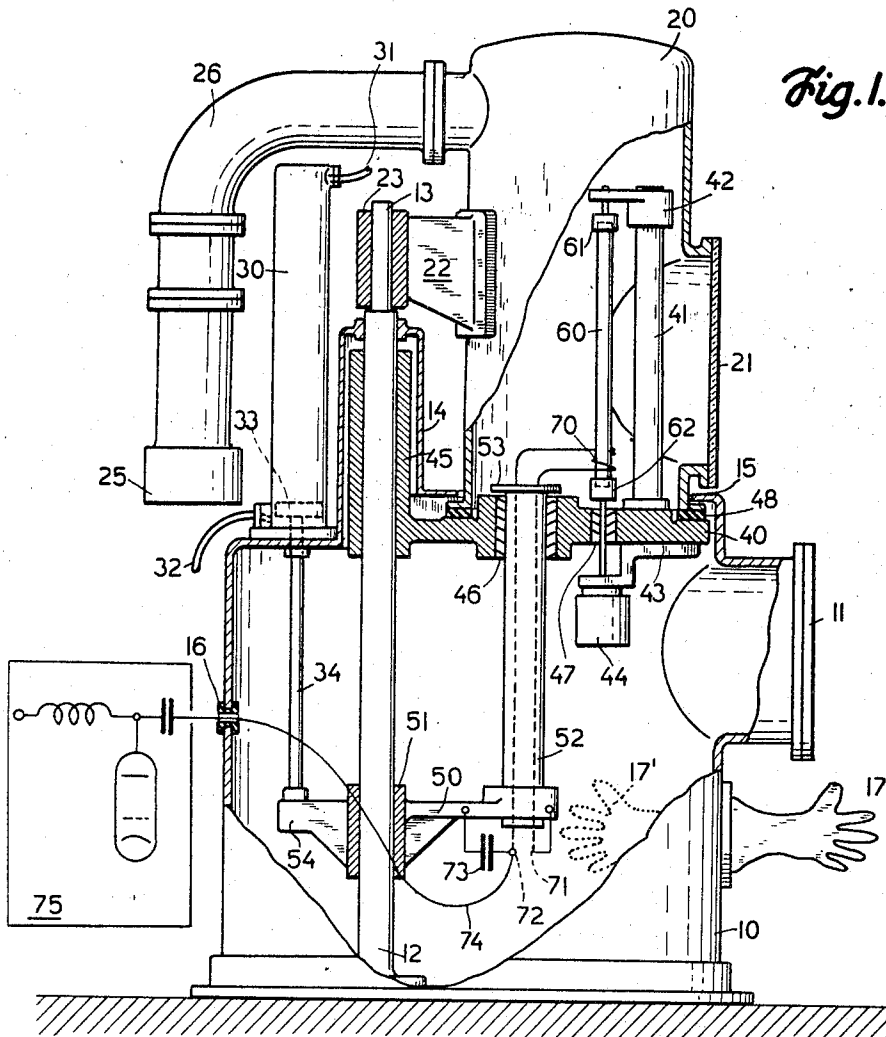
K. REGNER ETAL

3,410,945

APPARATUS FOR ZONE MELTING OF SEMICONDUCTOR BODIES
THROUGH HIGH-FREQUENCY HEATING

Filed Oct. 8, 1965

2 Sheets-Sheet 1



INVENTORS
Karel Regner, Josef Petrášek
BY
Richard Lundquist

Nov. 12, 1968

K. REGNER ET AL

3,410,945

APPARATUS FOR ZONE MELTING OF SEMICONDUCTOR BODIES
THROUGH HIGH-FREQUENCY HEATING

Filed Oct. 8, 1965

2 Sheets-Sheet 2

Fig. 2.

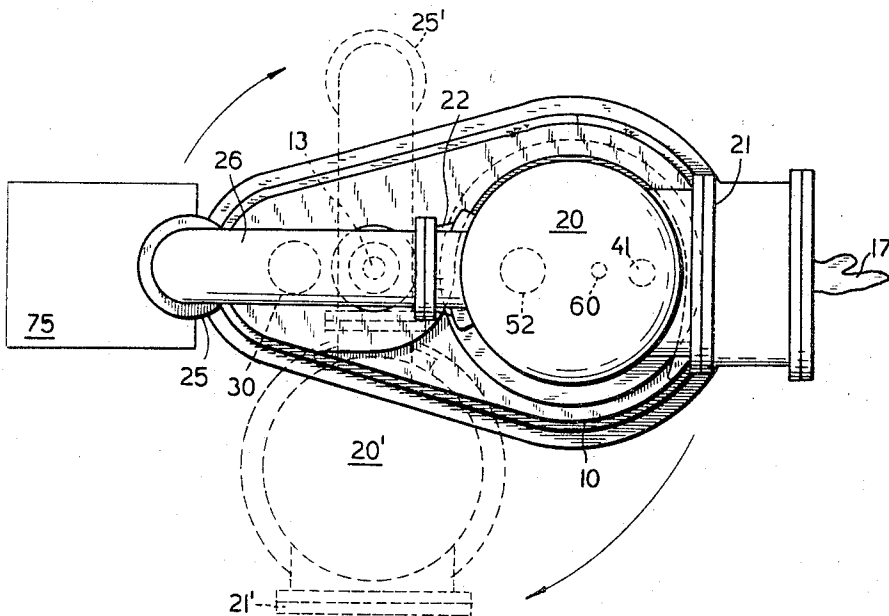
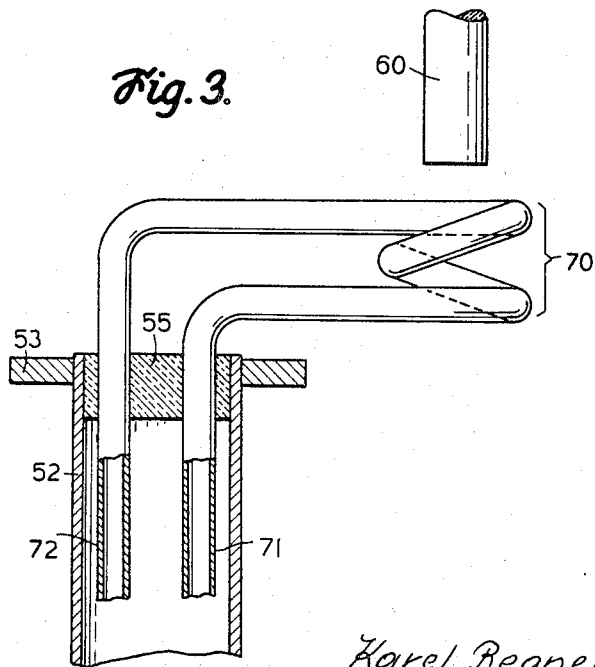


Fig. 3.



INVENTORS

Karel Regner, Jozef Pe-
BY trášek

Richard Lloyd
AQ't

1

3,410,945

APPARATUS FOR ZONE MELTING OF SEMICONDUCTOR BODIES THROUGH HIGH-FREQUENCY HEATING

Karel Regner and Josef Petrasek, Prague, Czechoslovakia, assignors to CKD Praha, oborovy podnik, Prague, Czechoslovakia

Filed Oct. 8, 1965, Ser. No. 494,025

Claims priority, application Czechoslovakia, Oct. 17, 1964, 5,749/64; Apr. 7, 1965, 2,281/65

7 Claims. (Cl. 13—1)

ABSTRACT OF THE DISCLOSURE

In a zone melting apparatus there are provided an enclosure and a bell, the latter being on top of the former and being separated from the former by a base wall which is slidably arranged and adapted to provide when it engages a rim of the bell a vacuum-tight seal between enclosure and bell. The bell defines a melting chamber. A rod-shaped object which is to be heated to its melting point is held within the bell. An induction coil surrounds said object and is slidable therealong. A flexible cable passes through a bushing in the enclosure wall and connects the power supply to a coaxial lead of the coil. A carrier within the enclosure is hydraulically operated to be raised and to move along with it the base wall and the induction coil. The rod-shaped object is rotated as the induction coil moves along said object. When the base wall sealingly engages the bell, the melting chamber is evacuated. When the induction coil is deenergized, and the vacuum in the sealed melting chamber broken by opening the chamber, the carrier returns to its starting point and a new cycle may begin. The rods to be heated are introduced into the enclosure through an opening therein.

This invention relates to the zone melting of semiconductor bodies, and more particularly to an apparatus for the zone melting of rod-shaped semiconductor bodies by a high-frequency electric field.

It is known to pass semiconductor rods through induction coils energized by high frequency current so that the portion of the rod contained within the coil is heated to its melting point by the induced current. Passage of the molten zone along the rod causes the impurities in the material to congregate at one end of the rod where they can be sawed off.

The semi-conductor body must be kept in a vacuum or other protective atmosphere while being subjected to zone melting, and the necessity of performing the process in a sealed chamber presents numerous problems which have not heretofore been solved in a fully satisfactory manner.

If the induction coil is fixedly mounted and the semiconductor rod is moved through the coil, electrical connections to the coil can be provided in a very convenient manner, but the sealed chamber must have a length twice that of the longest rod to be treated and additionally allowing for the holders which secure the two ends of the rod. Chambers as long as two meters have been built for zone melting with a stationary induction coil. Such a long chamber is not only costly to build and difficult to handle, but is difficult to clean of the impurities which tend to accumulate on the chamber walls.

The known devices which employ a movable induction coil traveling along a rod held stationary in a suitable holder are of two types. In one type, the rod to be treated is enclosed in a shell in which the necessary atmosphere is maintained, while the coil envelops both the shell and the rod. The presence of the shell between the coil and the object to be treated, however, prevents full utilization of the power input.

2

In the other known type of zone melting apparatus employing a moving coil, the coil is enclosed in the sealed chamber with the rod to be treated, but problems arise in the connection between the coil and its power supply which is necessarily located outside the chamber. The supply leads are quite long, and their impedance changes as they move with the coil in the chamber.

It is an object of this invention to improve the last-mentioned type of zone melting apparatus, and to overcome the problems inherent in the conventional power leads.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings in which—

FIG. 1 is a partial section elevation with a diagrammatic representation of current supply;

FIG. 2 is a plan view with the bell turned aside, diagrammatically represented by dashed contours;

FIG. 3 is an enlarged detail of the high-frequency circuit upper end together with a portion of the rod to be treated.

Referring to the drawing in detail, there is seen an enclosure 10 whose top is partly open. A heavy column 12 rises from the bottom of the enclosure through the space enclosed thereby, and projects upward through the closed portion of the enclosure top 14. A sleeve 23 is rotatably mounted on the free top end 13 of the column 12 which is of reduced diameter, thus securing the sleeve against downward movement.

A bracket 22 fixedly attached to the sleeve 23 carries a downwardly open bell 20. It will be understood that the bell is equipped with a jacket connected to a source of cooling water, as is conventional in this art, but the jacket has been omitted from the drawing for the sake of clarity. A window 21 sealed to the bell 20 permits observation of the interior of the bell. A duct 26 flanged to the bell carries a diffusion pump 25, the arrangement being such that the pump approximately balances the weight of the bell 20, and the center of gravity of the elements supported on the bracket 22 is located close to the vertical axis of the column 12.

A resilient sealing ring 48 on the free rim of the bell 20, this rim abutting against a covering margin 15, provides a vacuum-tight connection between the bell and a base wall 40 in the illustrated position of the apparatus. The base wall is mounted on a sleeve 45 which is freely slidable on the column 12 within the enclosure 10, and is held in the illustrated position against the evacuated bell 20 by external air pressure in the enclosure 10 so as to close the open top of the enclosure 10. Two vertical openings through the wall 40 respectively receive sealing bushings 46, 47.

A vertical stand 41 on the base wall 40 within the bell 20 carries a bracket 42 on its free top end. An upper rod holder 61 depends from the bracket 42. The stem of a lower rod holder 62 vertically passes through the sealing bushing 47, and is attached to an electric motor 44 which is secured to a bracket 43 in the enclosure 10. The two ends of a silicon rod 60 or other semiconductor object of similar configuration are respectively held by the holders 61, 62 in a known manner, the holder 61 being rotatably mounted on the bracket 42. The device which adjusts the vertical spacing of the holders 61, 62 during zone melting has not been shown since it may be entirely conventional.

A vertical piston 52, comprising rigid conductors 71, 72 is movably received in the sealing bushing 46. The upper piston end is provided with a collar 53 to limit the downward movement of the piston. The lower piston end is fixedly attached to a carrier bracket 50 integral with a sleeve 51 which is freely slidable on the column 12 under

the sleeve 45. The rigid conductors 71, 72 are fixedly secured in the piston through the medium of a plug 55 in the usual manner (see FIG. 3). An induction coil 70 which coaxially envelops the rod 60 is integral with the two rigid conductors 71, 72. The conductor 71 is grounded through the column 12, and a bank of capacitors 73 is interposed between the conductor 72 and ground at the bottom end of the piston 52 in the enclosure 10.

The high-frequency power supply for the oscillator circuit constituted by the coil 70, the capacitor 73, and the conductors 71, 72 have been diagrammatically illustrated, only the power source 75 comprising an output tube being shown in the drawing. A flexible cable 74 passing through a bushing 16 in the enclosure wall connects the power supply to the cable 72. The piston rod 34 of a piston 33 adapted to slide within a jack 30, is attached to a lug 54 in the carrier bracket 50. To the upper and lower ends of the jack 30 respective pressure fluid conduits 31 and 32 are connected. An air lock 11 on the enclosure 10 permits material to be introduced into the enclosure 10 where it may then be handled by an operator placing his hands from the outside into gloves 17 (17') which are sealed to the inner wall of the enclosure 10, only one glove being visible in the drawing.

The afore described apparatus is operated as follows:

The coil 70 is energized by the power supply while a vacuum is being maintained by the pump 25 in the sealed chamber enclosed by the bell 20 and the base wall 40. Hydraulic fluid is admitted through a conventional control valve (not shown) and the conduit 32 into the jack 30 so as slowly to raise the carrier bracket 50, whereby the coil 70 passes axially upward along the rod 60, sequentially melting portions of the rod in the usual manner. The rod is rotated during melting by the motor 44, and necessary adjustments are made in the spacing of the holders 61, 62 in order to maintain the original diameter of the rod during melting by means of the non-illustrated device referred to above.

When the coil 70 has completed its traverse of the rod 60, the sleeve 51 abuts from below against the sleeve 45, and holds the base wall 40 when the coil 70 is de-energized, and the vacuum in the sealed chamber is broken by opening of a non-illustrated vent cock.

When the hydraulic controls are set to drain fluid from the jack 30, the carrier 50 and the base 40 with the devices supported thereon descend to the illustrated position of the carrier 50, the coil 70 still being closely adjacent the bracket 42. An operator may now place his hands in the gloves 17' and replace the treated rod 60 by a fresh rod which is introduced into the interior of the enclosure 10 through the air lock 11.

The hydraulic control valve is next reversed, and the carrier 50 together with the base wall 40 are raised until the base wall sealingly engages the rim of the bell 20, whereupon the sealed chamber so formed is evacuated, and the base wall 40 is held in place by the vacuum while the carrier 50 is returned to the illustrated starting position. A new cycle may begin.

The melting chamber is thus opened and closed by the same hydraulic motor which also moves the coil 70. The provision of a single motor for both purposes reduces the bulk, and particularly the overall height of the apparatus, and contributes to its stability and freedom from vibrations, a serious source of difficulties in some known zone melting devices.

It will be understood that a non-illustrated pin passes through radially aligned openings in the sleeve 23 and the column 12 under all normal operating conditions of the apparatus to prevent pivotal movement of the bell 20 on the column 12. When it is desired to clean the bell, the carrier 50 and base wall 40 are fully lowered, the pin is withdrawn, and the bell is swung on the column 12 until it clears the enclosure 10, whereby free access to the interior of the bell is had from below, and impurities

scraped from its inner wall may be dropped into a suitably placed container.

The interior of the enclosure 10 is supplied with dry, filtered air in a manner not further illustrated to avoid contamination of the rods 60. A supply of several rods to be treated is normally introduced simultaneously into the enclosure through the air lock 11, and all rods are withdrawn together after treatment to minimize the hazards of contamination during transfer. Obviously, mechanized rod insertion and rod removal devices may be installed within the enclosure 10 in a manner not in itself relevant to the instant invention.

The apparatus of the invention combines the advantages of the conventional moving-rod zone melting devices with those of the known devices using a moving coil. The power supply is connected with the oscillator circuit by a flexible conductor, yet the heating output and the frequency of the oscillator are stable. The variations in the impedance of the flexible conductor 74 during coil movement do not significantly affect the stability of the operating parameters because the current in the conductor 74 is small as compared to the current flowing in the oscillator circuit. The elements of the latter, namely the coil 70, the capacitor bank 73, and the conductors 71, 72 rigidly maintain their spatial relationship through all phases of the operating cycle.

The elements which move during opening and closing of the sealed chamber in the apparatus of the invention are relatively light. The heavy bell which has to withstand most of the atmospheric pressure against the evacuated apparatus, and further carries the heavy water jacket (not shown) remains stationary during normal operation of the apparatus. It does not move vertically under any condition. It is readily pivoted by hand for cleaning and similar maintenance purposes. No special devices are needed for holding the base wall to the bell.

The provision of a movable base wall permits all manipulations of the rods 60 to be performed in the enclosure 10 which may be made gas tight, or which may be flooded with clean dry air or other gas at a sufficient rate to prevent entry of ambient contaminants such as dust through small openings.

The modifications of the illustrated apparatus necessary for use of a different protective atmosphere will be obvious.

It should be understood, of course, that the foregoing disclosure relates only to a preferred embodiment of the invention and that it is intended to cover all changes and modifications of the example of the invention herein chosen for the purpose of the invention which do not constitute departures from the spirit and scope of the invention set forth in the appended claims.

What is claimed is:

1. In a zone melting apparatus, in combination:

(a) wall means defining a closed chamber, said wall means including

(1) a base wall and bell means, said base wall being formed with an opening,

(b) moving means for moving said base wall and said bell means relative to each other toward and away from a position wherein said base wall and said bell means sealingly engage each other to define said chamber,

(c) a fixed support, said base wall and said bell means being mounted on said support,

(d) holder means in said chamber for holding a rod-shaped object in such a manner that the longitudinal axis thereof extends in a predetermined direction,

(e) an enclosure, said moving means including

(1) means for moving said base wall in said predetermined direction on said support inward of said enclosure when said base wall is moved away from said bell means, and

(2) air lock means on said enclosure for giving access to said holder means when the same is

5

- moved into said enclosure with said base wall,
- (f) elongated lead means movable in bearer means in said chamber,
 - (g) actuating means for moving said lead means longitudinally in said predetermined direction,
 - (h) an induction coil fixedly mounted on said lead means in said chamber, said coil being positioned to envelop a rod-shaped object held by said holder means,
 - (i) a capacitor fixedly mounted on said lead means, said capacitor, said lead means, and said coil being conductively connected to constitute an oscillator circuit, and
 - (j) means for supplying power to said circuit.
2. In an apparatus as set forth in claim 1, a carrier mounted on said support and operatively connected to said actuating means for movement thereby in said direction, said lead means being attached to said carrier.
3. In a zone melting apparatus, in combination:
- (a) a support;
 - (b) bell means and a base wall mounted on said support, said base wall being movable in a predetermined direction on said support toward and away from a position of sealing engagement with said bell means in which said base wall and said bell means jointly define a closed chamber, said base wall being formed with an opening extending there-through in said direction;
 - (c) pump means for evacuating said chamber;
 - (d) a carrier mounted on said support outside said chamber;
 - (e) a lead extending through said opening, said lead being elongated in said direction and having respective portions in said chamber and outside said chamber, the latter portion being mounted on said carrier;
 - (f) actuating means for moving said carrier on said support in said direction;
 - (g) holder means on said base wall for holding an

6

- elongated object in such a manner that the object is elongated in said direction;
- (h) an induction coil mounted on the portion of said lead in said chamber and positioned to envelop an elongated object held by said holder means;
 - (i) a capacitor mounted on said lead; said capacitor, said lead, and said coil being conductively connected to constitute an oscillator circuit; and
 - (j) power supply means for said circuit.
4. In an apparatus as set forth in claim 3, said lead being rigid.
5. In an apparatus as set forth in claim 4, said holder means including means mounted on said base wall for rotating an elongated object held by said holding means about the longitudinal axis thereof, while enveloped by said coil.
6. In an apparatus as set forth in claim 4, an enclosure having an open side, said base wall when in said position substantially closing said open side, a portion of said support and said carrier being received in said enclosure, and said holder means being adapted to be received in said closure when said base wall moves away from said position thereof; and air lock means on said enclosure for access thereto.
7. In an apparatus as set forth in claim 4, cooperating abutment means on said carrier and on said base wall engageable for moving said base wall toward said position thereof when said carrier is moved in said direction by said actuating means.

References Cited

UNITED STATES PATENTS

2,972,525	2/1961	Emeis.	
3,270,177	8/1966	Prediger et al.	13—1 XR

BERNARD A. GILHEANY, *Primary Examiner*.R. N. ENVALL, Jr., *Assistant Examiner*.