

April 17, 1962

R. EMEIS

3,030,194

PROCESSING OF SEMICONDUCTOR DEVICES

Filed Feb. 11, 1954

2 Sheets-Sheet 1

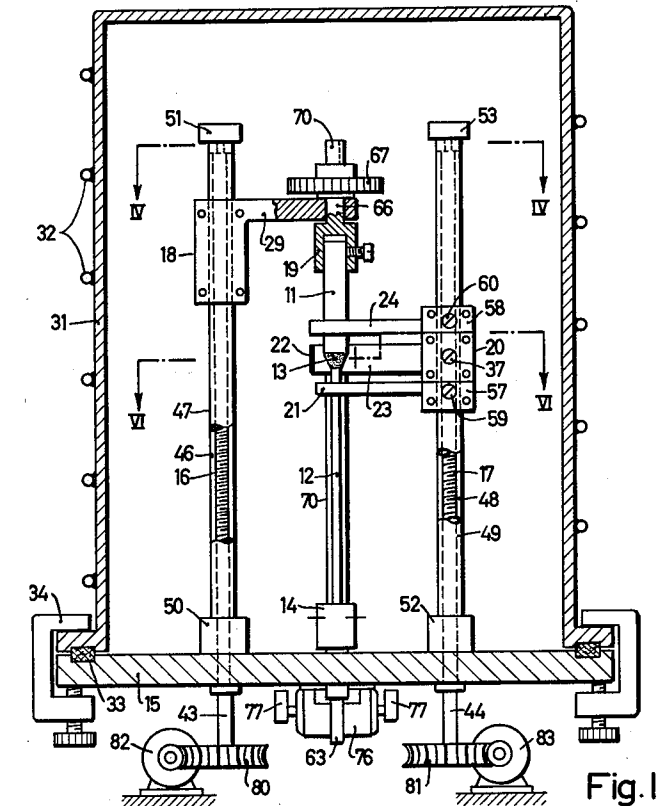


Fig. 1

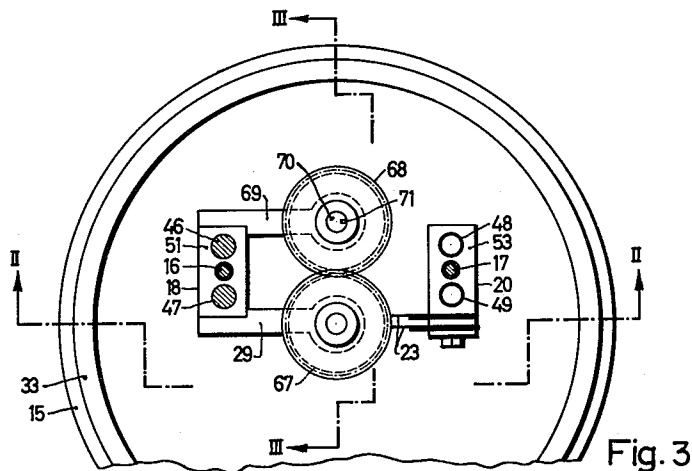


Fig. 3

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2 Sheets-Sheet 2

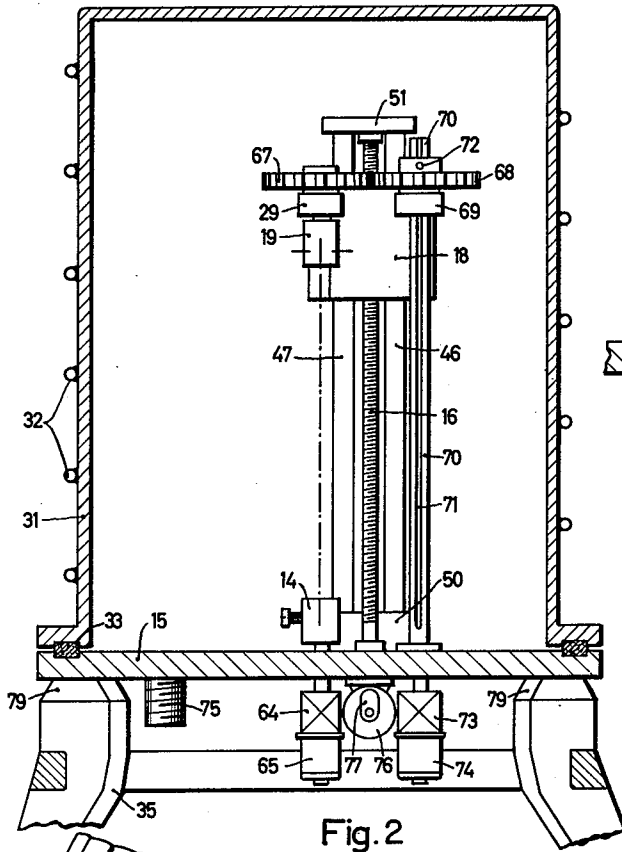


Fig. 2

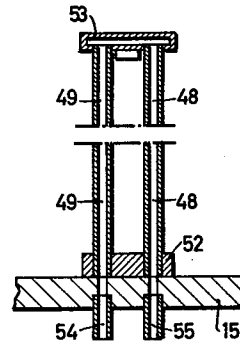


Fig. 6

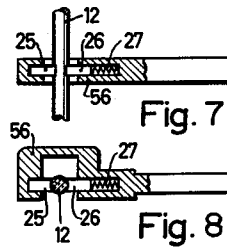


Fig. 7

Fig. 8

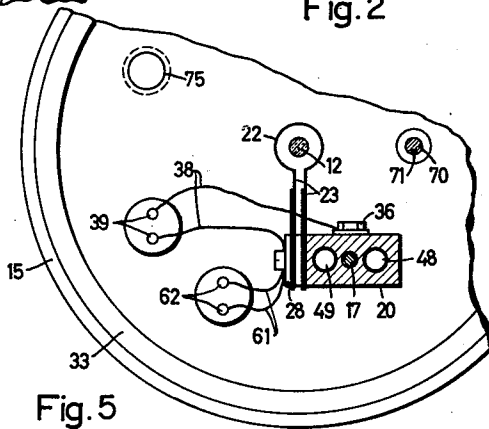


Fig. 5

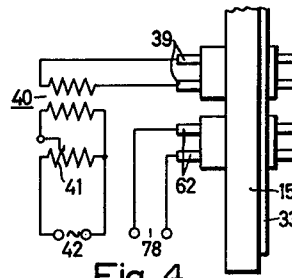


Fig. 4

1

3,030,194

PROCESSING OF SEMICONDUCTOR DEVICES

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5 Claims. (Cl. 23—301)

My invention relates to a method for the crucible-free zone pulling of an elongated, particularly rod-shaped body of crystalline substance, preferably semiconductor substance.

My invention represents an improved zone-melting process and is preferably applicable for substances of a very high melting point, such as silicon, with which the use of a crucible involves difficulties, my process according to the invention is also suitable for the preparation of germanium and semiconductive crystalline compounds such as aluminum antimonide.

In my process the ends of a crystalline rod are fixed in radial direction relative to each other, and a cross-sectional zone of small thickness is liquefied by heating while avoiding a crucible or the like. The heating device required for this purpose, and the melting rod are moved relative to each other in the longitudinal direction of the latter, so that the melting zone travels lengthwise through the rod. Simultaneously the rod ends are moved relative to each other in the direction of the rod axes for influencing the cross-sectional shape of the melting body.

The starting material for the process according to the invention, preferably in the form of a rod, may be produced in any conventional manner, for instance, by press-molding a powder of pure semiconductive material or materials, together with a binding agent, if necessary, and subsequently sintering. Such bodies in most cases have a relatively large cross section, in the order of 1 cm.². This is many times the area desired of the finished semiconductor elements, which usually consist of small discs of a few square-millimeters in area equipped with the necessary contacts or electrodes for use as crystal detectors, rectifiers, transistors, phototransistors, varistors and the like. For that reason, the cross sectional area of the material resulting from the known melting operation must be subdivided several times by mechanical means, for instance by sawing. The subdividing operation is time-consuming and requires a great amount of care aside from causing considerable waste in the form of chips and dust.

It is another object of my invention to obviate these disadvantages and to greatly simplify the manufacture of semiconductor discs as needed for the various, above-mentioned applications.

To this end, and according to another feature of my invention, the zone-melting process mentioned in the foregoing is modified by moving the ends of the semiconductor material rod away from each other during the zone-melting operation so that the cross section of the zone-melted finished rod is smaller than that of the original material. As a result, the number of subsequent operations needed for reducing the cross sectional area is reduced. Such subsequent operations may also be completely obviated by reducing the cross sectional area of the material being zone-melted to the final size of the disc-shaped semiconductor bodies to be produced, this reduction being obtained by applying a suitable velocity to the relative movement of the rod ends away from each other. If desired, this result may also be obtained by applying several successive drawing operations whereby the cross section is reduced in a stepwise manner. The final product of the zone-melting process need only be

2

subdivided in the axial direction simply by sawing disc-shaped parts or slices off the body of material processed.

For the reasons given, the production of a zone-melted body of semiconductive material of at most 10 square-millimeters in cross-sectional area in accordance with the invention results in a considerable simplification in manufacturing. When the cross section of the body after completion of the zone-melting treatment is not larger than 5 square-millimeters, a further subdivision of the cross section is often not required so that the desired discs of material may be directly severed from the body. However, rods of smaller cross section can also be produced, for instance rods having cross sections of 1 square-millimeter and less.

The foregoing and other objects, advantages and features of the invention will be apparent from, and will be set forth in, the following description in conjunction with the drawings in which:

FIG. 1 shows a sectional front view of an embodiment of a complete processing device according to the invention, the section being taken along the line II—II indicated in FIG. 3;

FIG. 2 shows a side view thereof, also in section, the section being taken along the line III—III in FIG. 3;

FIG. 3 shows a cross section seen from the top along the line IV—IV in FIG. 1, the bell-shaped housing of the device being removed;

FIGS. 4 and 5 show details relating to the electrical connections and circuits of the device; and

FIGS. 6, 7 and 8 show separately a number of individual parts of the device.

Referring to FIGS. 1 to 8, the rod of semiconductive material to be treated is shown in an intermediate stage of the processing procedure in which this rod has a relatively thick upper portion 11 and a relatively thin lower portion 12 (FIG. 1). That is, the portion 12 has already passed through the zone-melting process so that its cross section has become reduced in comparison with the original cross section of the upper rod portion 11. The material in the melting zone 13 is liquid and forms a drop. A holder 14 for the lower rod portion is revolvably mounted on a base plate 15 and is vacuum-tightly sealed at the base plate. The plate 15 forms the bottom of a recipient within which the process is carried out in vacuum or in an atmosphere of inert gas. To this end, the base plate 15 is provided with a nipple 75 (FIG. 2) for connection to a high-vacuum pump or to a gas tank. The bell 31 of the recipient consists of steel. A cooling coil 32 of copper tubing forms several turns around the bell and is soldered thereto. The cooling coil 32 may be connected to a water supply pipe. The bell is sealed by means of a gasket ring 33 and is held pressed against the base plate 15 by screw clamps 34 (FIG. 1). The base plate 15 has rubber feet 79 resting upon a three-legged support 35 so that the base plate is readily accessible from below.

Two screw spindles 16 and 17 pass revolvably and vacuum-tightly sealed through respective openings of the base plate 15. An internally threaded support 18 of brass, in threaded engagement with the spindle 16, carries a holder 19 for the upper end of rod portion 11. Holder 19 is joined with support 18 by means of an arm 29 consisting preferably of insulating material. Another support 20, also of brass, is mounted on the spindle 17 in threaded engagement therewith. Support 20 carries the heating device. The supports 18 and 20 slide along guiding frames each consisting of two steel rods 46, 47 and 48, 49 respectively, of circular cross section. Two cross bars 50 and 51 interconnect the rods 46 and 47 at both ends respectively. Corresponding cross bars 52 and 53 interconnect the ends of the pair of rods 48 and 49. The rods 48 and 49 that guide the support 20 for

the heating device are preferably designed as tubes according to FIG. 6. The upper openings of the tubular rods communicate with each other through a duct in the interior of the cross bar 53. The lower openings are connected through respective bores in base plate 15 with nipples 54 and 55 through which cooling water is circulated through the rods.

In the illustrated embodiment, a ring-shaped heating device consisting of an annularly bent strip 22 of tungsten is energized by electric current in the order of magnitude of 100 amps. It will be noted that the heating is by heat radiation since, as stated above, contact of the molten material with apparatus elements is to be avoided. The temperature of the heater is controlled depending upon the melting point of the semiconductor material. This temperature, for instance, is about 2000° C. for silicon, corresponding to a melting point of approximately 1400° C. The melting points for germanium and the semi-conductive compounds are lower, in part below 1000° C. so that the temperature of the ring-shaped heater may be correspondingly lower. The liquid zone of the semiconductor rod, therefore, has the melting temperature of the particular substance being processed. The time of the heating treatment results from the velocity at which the heating device is moved along the rod as specified in this disclosure.

Current is supplied to the heater ring 22 by means of terminal lugs 23 integral with the heater ring. The lugs 23 are clamped to the support 20 by means of a copper plate 28 with an intermediate layer of mica. The plate 28 is fastened to support 20 by means of insulated screws. The current-conducting cross section of the terminal lugs 23 can be doubled by back-folding the clamped ends as is apparent from FIG. 5. The support 20 and the plate 28 carry respective terminals 36, 37 for the connection of flexible current supply cables 38 leading to conductor pins 39 (FIG. 5) that extend vacuum-tightly through the base plate 15. The current supply cables are only schematically represented in the drawing (FIG. 5). They consist preferably of uncovered Litz wire with short tubular pieces or beads of glass strung upon them to provide the necessary insulation as well as a sufficient flexibility. The lead-in pins 39 are connected with the high-current output winding of an auxiliary transformer 40 (FIG. 4) having a primary winding energized through a variable autotransformer 41 from the terminals or buses 42 of an alternating current line so that the output voltage can be adjusted between zero and, for instance, 10 volts. The temperature of the heater is thus controlled by the variable autotransformer.

The respective shaft ends 43 and 44 of the threaded spindles 16 and 17 are driven through suitable transmissions, for instance the illustrated worm gears 80 and 81, from small direct-current shunt motors 82, 83. These motors may be mounted on the support 35 in any suitable manner. The ratio of the revolving speeds of motors 82 and 83 is so adjusted that the support 20 moves upwardly at a greater velocity than the support 18. For instance, the heating device 22 and its support 20 may move upwardly at a speed in the order of 0.5 to 5 mm. per minute. When the upper holder 19 and its support 18 are moved upwardly at half the speed of support 20, then the cross section of the lower rod portion 12 becomes about half as large as that of the upper rod portion 11. By a corresponding selection of the speeds, the rod-shaped body being zone-melted can be drawn to a cross section of any desired thinness. The ratio of the revolving speeds may also be adjusted by a mechanical transmission or by an automatic electric control and, if desired, this speed ratio may be varied at will or may be automatically regulated during the zone-melting operation.

Also mounted on support 20, by means of a clamping plate 57, is a guiding device 21 for the free end of the lower rod portion 12. According to FIGS. 7 and 8, the

clamping device 21 comprises a holder 56 that forms a semi-annulus about the rod portion 12 and carries two guide fingers 25 and 26 of which one is resiliently displaceable and biased by a pressure spring 27. The guide fingers 25 and 26 may consist of carbon or aluminum oxide. They are preferably cylindrically recessed where they come into slidable engagement with the rod portion 12. The guide fingers maintain the free end of rod portion 12 axially aligned with the heating device and with the upper rod portion 11. However, if the cross section of the treated body is larger than 5 square-millimeters, it is, as a rule, unnecessary to provide additional means for guiding the rod during the processing operations.

Another guiding device 24 is provided for the upper rod portion 11. The guiding device 24 is similar to device 21 and is mounted on support 20 by means of another clamping plate 58. The guiding devices 21 and 24 may also serve as means for supplying an electrical current in the order of a few amperes to be additionally passed through the melting zone 13. To this end, the holders 56, consisting of a conductive material such as brass, are in conductive contact with the clamping plates 57 and 58 also consisting of conductive material, but are insulated from the support 20 and the fastening screws by an intermediate insulating layer of heat-resistant material such as mica. The clamping plates 57 and 58 are provided with terminal screws 59, 60 that are connected by leads 61 to vacuum-tightly sealed lead-in terminals 62 traversing the base plate 15 (FIG. 5). The lead-in terminals 62 are connected to a direct-current or alternating-current source.

The device is further equipped with means for revolving the rod portions 11 and 12. To impart such a revolution to the rod ends, the shaft end 63 of the holder 14, vacuum-tightly journaled to the base plate 15, is coupled by a gear transmission 64 with a drive motor 65. The upper holder 19 is also provided with a shaft end 66 (FIG. 1) which is journaled in the bore of the supporting arm and carries a spur gear 67. Another spur gear 68 is journaled on a supporting arm 69 (FIGS. 2, 3) mounted on support 18. Gears 67 and 68 are continuously in meshing engagement with each other. A shaft 70 with a longitudinal groove 71 (FIGS. 1, 2, 3) passes through a central bore in the hub portion of spur gear 69. A pin 72 screwed into the hub portion of spur gear 68 engages the groove 71, so that spur gear 68 is entrained by the revolving shaft 70 while being capable to slide upwardly and downwardly along the shaft. Shaft 70 has its lower end vacuum-tightly journaled in the base plate 15. The shaft end, extending through the base plate, is connected by a gear transmission 73 with a drive motor 74. The apparatus for rotating the rod ends just described makes it possible to drive the upper rod portion 11 alone or the lower rod portion alone or both rod portions simultaneously, either in the same direction or in opposite directions of revolution, and at any desired speed between 0 and 1000 or more revolutions per minute. This permits modifying the shape and consistency of the melted zone in various ways. It is also possible, for instance, to cause impurities, that may be included in undissolved condition within the melted zone, to migrate due to centrifugal force to the rod surface, from which subsequently such impurities may readily be removed. That is, any undissolved foreign substances in the interior of the melted zone, for instance particles of silicon carbide, having a higher specific gravity than the melted material, when subjected to a sufficiently high speed of revolution, are moved by centrifugal force to the exterior surface of the body. By subsequent etching of the processed body, such inclusions can be laid open and can easily be removed mechanically, for instance, by scraping.

Rotary movement occurring for long periods of time at a speed coinciding with the natural frequency of the

5

melted material in the melting zone should be avoided. For that reason, the speed of revolution is preferably so chosen that it lies either below or above the resonant revolving speed. For practical purposes, a revolving speed of 300 to 400 revolutions per minute has been found particularly suitable. However, after a relatively rapid and hence non-detrimental passage through the resonance range, revolving speeds over 1000, particularly up to 2000 revolutions per minute can be applied.

In certain cases, it may be desirable to vary the revolving speed during the processing in order to definitely control the build-up of the zone-melted body in its longitudinal direction, as for instance, when supplying the body with substitutional impurities, namely donors and/or acceptors.

It will be recognized that either the upper rod portion or the lower rod portion may be placed in revolution by imparting a revolving movement to the appertaining holder. If one rod portion revolves while the other remains at rest, the revolving speed distributes itself within the melting zone and in the axial direction of the rod being processed in such a manner that the speed value declines, from the limit value determined by the speed of the revolving portion down to the limit value zero of the stationary portion, in a continuous and approximately linear progression. However, both rod portions may be revolved simultaneously either in the same direction or in opposing directions. The latter case results in the advantage that the speed distribution within the liquefied zone passes through the zero value at a place between the two limit values. At this place, therefore, no centrifugal force will occur. The position of this place results from the ratio of the revolving speeds of the two rod portions. With equal revolving speeds and mutually opposed directions of revolution, the location of zero centrifugal force lies just in the center of the melting zone, that is, at the hottest point, where otherwise the danger of liquid particles of material dropping off or being flung off is greatest. This danger is effectively counteracted by the mutually opposed revolution of the two rod portions.

In certain cases, the texture of the zone-melted body to be produced can be improved by imparting vibration to the liquid zone during the processing period. Such vibrations are produced by a shaker motor 76 whose shaft ends carry eccentric unbalanced masses 77. The shaker motor 76 is mounted on the base plate 15.

It will be obvious to those skilled in the art, upon study of this disclosure, that my invention permits of various modifications other than those specifically illustrated and described, without departing from the essence of my invention and within the scope of the claims annexed hereto.

I claim:

1. The method of processing an elongated piece of crystalline semiconductor material, comprising heating a cross-sectional zone of said piece of material to a temperature high enough for liquefaction thereof, moving said zone-heating axially with respect to said piece of material, while simultaneously reducing the cross-sectional diameter of substantially the entire processed piece by continuously moving the ends of said piece relatively away from each other.

2. A process for the production of disc-shaped semi-

6

conductor elements used in electrical transistors and the like from an elongated piece of crystalline semiconductor material, comprising heating a cross-sectional zone of said piece of material to a temperature high enough for liquefaction thereof, moving said zone-heating axially with respect to said piece of material while at the same time continually moving the ends of said piece away from each other so that the processed piece is uniformly of substantially reduced cross-sectional diameter, and then slicing said processed piece to form the disc-shaped elements.

3. The process of successively zone-melting and re-solidifying an elongated body of fusible semiconductor material which comprises supporting said body at both end portions in a vertical position, applying heat to establish a molten zone extending throughout the entire cross-section of the body, the length of said molten zone being such that the molten material is prevented from escaping solely by virtue of cohesive and adhesive forces, displacing said molten zone in an axial direction along said body, and reducing the cross-sectional diameter of substantially the entire processed body by moving in the axial direction at least one of the end portions relative to the other during the melting.

4. The process of successively zone-melting and re-solidifying an elongated body of fusible semiconductor material which comprises supporting said body at both ends in a vertical position, applying heat to establish a molten zone extending throughout the entire cross-section of the body, the length of said molten zone being such that the cohesive and adhesive forces in the molten material are sufficient to overcome the weight of the molten material of said zone, displacing said molten zone in an axial direction along said body, and reducing the cross-sectional diameter of substantially the entire processed body by subjecting at least one of the end portions to pulling stress axially away from the other during the melting.

5. The method of processing an elongated piece of crystalline semiconductor material, comprising heating a cross-sectional zone of said piece of material to a temperature high enough for liquefaction thereof, moving said zone-heating axially with respect to said piece of material, while simultaneously reducing the cross-sectional diameter of substantially the entire processed piece by continuously moving the ends of said piece relatively away from each other, and repeating the treatment of said process piece to produce a final cross-sectional area of less than five square millimeters.

References Cited in the file of this patent

UNITED STATES PATENTS

2,254,306	Mott et al. -----	Sept. 2, 1941
2,419,373	Schrumm -----	Apr. 2, 1947
2,686,864	Wroughton et al. -----	Aug. 17, 1954
2,739,088	Pfann -----	Mar. 20, 1956

FOREIGN PATENTS

1,065,523	France -----	Jan. 13, 1954
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OTHER REFERENCES

Keck and Golay: *Phy. Rev.*, vol. 89, page 1297, March 15, 1953 (effective date Jan. 27, 1953).