Feb. 26, 1963 W. WENDE 3,078,549

METHOD OF PRODUCING SEMICONDUCTOR WAFERS

Filed March 24, 1959

Fig. 1

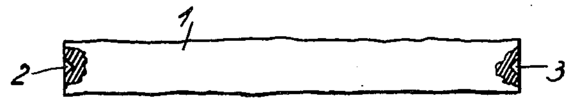


Fig. 2

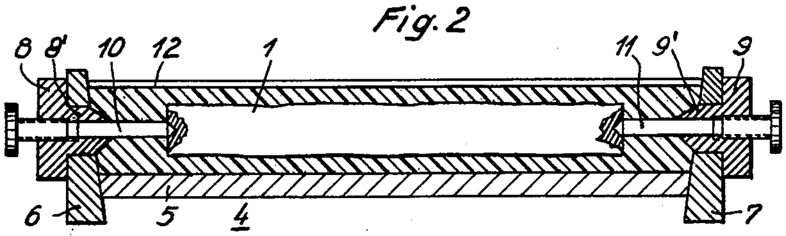


Fig. 3

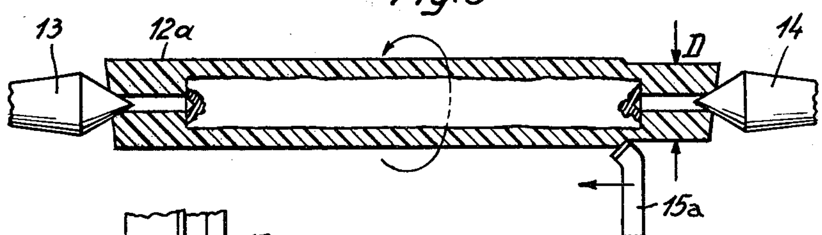


Fig. 4

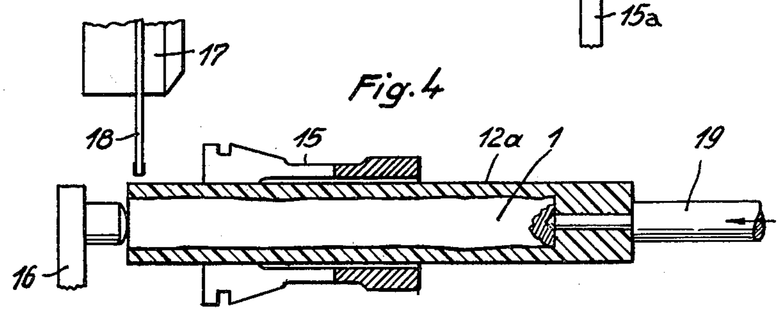
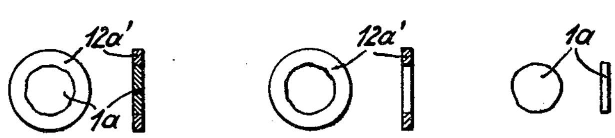


Fig. 5 Fig. 6 Fig. 7 Fig. 8



Inventor:

Walter Wende

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METHOD OF PRODUCING SEMICONDUCTOR WAFERS

Walter Wende, Berlin, Germany, assignor to Siemens-Schuckertwerke Aktiengesellschaft, Berlin-Siemensstadt, Germany, a corporation of Germany

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My invention relates to the production of crystalline wafers of semiconductor material, such as germanium or silicon for use in transistors, rectifiers and other electronic semiconductor devices.

Such wafers, in form of plates or circular discs, are obtained by slicing them from rod-shaped stock material previously made, for example, by a crystal-pulling or crystal-precipitating process and subjected to zone pulling for conversion from polycrystalline to monocrystalline constitution, and subsequently purified by zone pulling. In the slicing process it is difficult to obtain a clean cut, because the semiconductor materials, such as germanium or silicon are usually very brittle and fragile. This makes itself felt particularly near the end of each individual cut due to the tendency of the semiconductor to break away from the rod before the cut is fully completed. Such trouble cannot be avoided by holding the stock material at the slicing location upon a support, because the rod-shaped stock resulting from the above-mentioned manufacturing methods does not have accurate dimensions but, as a rule, has an irregular, wavy surface, the irregularities extending mainly in the longitudinal direction which is identical with the direction of the pulling processes.

It is an object of my invention to reliably eliminate the above-mentioned difficulties by relatively simple means and to secure uniformly satisfactory products.

To this end, and in accordance with a feature of my invention, the rod-shaped raw semiconductor stock material, possessing the above-mentioned irregularities, is provided with a jacket intimately joined with, and adherent to, the rod surface at least along that portion of the periphery where the last portion of the slicing cuts for producing the individual semiconductor wafers passes through the semiconductor material.

During the slicing process, the auxiliary jacket acts as a mechanical brace for the semiconductor wafer being severed from the rod material. The slicing cut for each wafer is completed only when the slicing tool has passed entirely through the semiconductor material and, in addition, has also cut through the jacket material intimately bonded to the semiconductor material. Consequently, the wafer resulting from the slicing operation is continuously supported mechanically and firmly kept in its original position until after the slicing tool has cut all the way through the semiconductor material.

It suffices, in principle, to provide the auxiliary jacket only at the location where the slicing cut is completed. However, it is preferable to envelop the semiconductor rod by the jacket material over the entire periphery, so that it is not necessary, when placing the jacketed rod into the slicing machine to secure the rod in any particular position for making certain that the auxiliary jacket is located where the slicing cut is completed.

The jacket substance used for the purposes of the invention consists of a material which is chemically inert or neutral relative to the pure germanium, silicon or other semiconductor material. Preferably suitable as jacket material are synthetic resins, and the jacket is applied to the semiconductor rod by compressing the synthetic plastic in form of a powder or paste about the rod, or by applying the synthetic material in liquid form, preferably as a casting resin. After hardening of the synthetic plastic, the jacket is machined at the peripheral surface to the desired stereometrically regular, preferably cylindrical, shape most suitable for the chuck or clamping device of the slicing machine. It is desirable that the jacket enveloping the semiconductor rod have approximately the same thickness at all localities. It is therefore preferable, according to another feature of the invention, to provide the raw semiconductor rod, before placing it into the jacket mold, with suitable bores or center-punched scores, preferably at both axial ends. This can be done by means of a drill or center punch of hard metal. The center bores are then used for holding the rod in a given position after it is placed into the mold. Thereafter, the plastic jacketing material in form of a liquid, powder or paste is fed into the mold and is permitted to cool or is subjected to the proper hardening or curing process, for example a heat treatment. As a result, the synthetic jacket material is conditioned to place itself intimately against the surface of the semiconductor rod and to form a firmly bonded, solid jacket of a given minimum thickness. For thus jacketing the semiconductor rod by synthetic plastic, any of the commercial casting resins can be used to advantage. Suitable for this purpose, for example, is the casting resin on epoxy basis available under the trade-name "Araldite."

The jacketed semiconductor rod is thereafter put on a machine tool, for example a lathe, and the center bores or center-punch holes previously used for holding the rod in the casting mold, are also used for centering the jacketed rod on the machine tool. Thereafter, the jacket of synthetic plastic is machined down to a desired diameter corresponding, for example, to the diameter suitable for the chuck of the slicing machine to be subsequently employed for cutting the rod into wafers. The machining operation permits giving the outer diameter of the jacketed rod a sufficiently accurate size to obtain not only an always reliable clamping of the rod in a chuck, but to also permit accurately displacing the rod axially a given amount when the chuck is opened only slightly.

Hence, a rod of semiconductor material thus provided with a jacket of synthetic plastic can readily be processed on an automatic slicing machine which, after severing a slice, loosens the chuck and then advances the jacketed rod through the chuck an amount corresponding to the thickness of the next wafer to be severed plus the thickness of the slicing tool. Such automatic advance is preferably effected up to a fixed stop. Thereafter the rod is again clamped fast in the chuck, and the next slicing operation is carried out. A diamond slicing disc or circular diamond saw is preferably used. During each slicing cut, the semiconductor material remains well supported and braced by a portion of the plastic jacket while the cutting tool passes through the last portion of the semiconductor material, thus preventing particles of semiconductor substances from breaking off the wafer being produced. After each individual wafer is completely cut off, the semiconductor disc can readily be loosened out of the plastic enclosing ring.

A simple method for thus separating the semiconductor wafer from the plastic enclosure is to place the severed disc into a liquid solvent consisting essentially of ethylene trichloride or acetone, for example. In such a bath, the plastic ring as a rule, separates itself automatically from the semiconductor body. This can be explained by the fact that the solvent acts as a swelling agent upon the plastic ring-shaped body so that this body widens its inner diameter and thus becomes separated from the semiconductor disc.

If desired, however, the plastic ring can also be removed by bending it out of the plane of the slice. This is so because, as has been found, the jacket of plastic material and the semiconductor body are not compatible in the sense of an adhesive bond, the mechanical bond between the jacket and the semiconductor rod being brought about, apparently, merely by shrinking of the synthetic material during hardening, which causes it to be tensioned and clamped fast upon the peripheral surface of the semiconductor rod.

For further explaining the invention, reference will be made to the drawing, illustrating an embodiment of the invention by way of example.

FIG. 1 shows schematically a raw semiconductor rod center scored at both ends.

FIG. 2 is a longitudinal section of a jacketing mold into which the rod is inserted.

FIG. 3 shows the jacketed rod during machining of its peripheral surface.

FIG. 4 illustrates the slicing operation performed on the jacketed and machined rod.

FIGS. 5 and 6 show, respectively, a front view and cross section of an individual slice obtained according to FIG. 4;

FIG. 7 is a cross section of the jacketing material removed from the remaining semiconductor disc illustrated in FIG. 8.

The raw monocrystalline semiconductor rod **1** (FIG. 1) of germanium or silicon, resulting from the above-mentioned crystal-pulling and zone-purifying process, has a wavy configuration, particularly in the direction parallel to its axis. The rod **1** is first provided on its two axial ends with center bores or scores **2** and **3**, for example by means of a hard-metal drill or center punch.

Then the rod *i* is placed into an auxiliary molding device in which the semiconductor rod is provided with a jacket of synthetic plastic. The device, according to the example shown in FIG. 2, is trough shaped and comprises a main portion **5** and two end closures **6**, **7**. Inserted into respective bores of closures **6** and **7** are the neck portions **8'**, **9'** of respective bushings **8**, **9**, so that these bushings are guided with a tight fit in the bores. Each of the bushings has a flange portion abutting against the outer surface of the closure **6** or **7**, and can be interlocked with the closure by means of a mechanical bayonet connection (not illustrated). The inner bore of each bushing **8**, **9** is provided on part of its axial length with an internal screw thread, the remaining portion of the bore being plain cylindrical. A screw bolt **10**, **11** is screwed into each bushing **8**, **9**. The inner end of the screw bolt **10**, **11** forms a conical tip. The end of each neck portion **8'**, **9'** is likewise conical and is so shaped that it will mold a conical cavity into the jacket material, which cavity corresponds to the conical tips between which the jacketed semiconductor rod is to be subsequently inserted on the lathe or other machine tool.

The semiconductor rod **1** is mounted between the two tips of the screw bolts **10**, **11** by turning the bolts toward and into the center scores **2**, **3** of the rod. In this manner, the rod is firmly held in a given position relative to the inner peripheral surface of the trough body **5**. Now the casting resin, if desired mixed with a suitable hardener, is filled into the remaining hollow space of the trough **5**, so that the plastic mass envelops the semiconductor rod **1** on all sides with a given minimum jacket thickness.

Prior to feeding the plastic mass into the trough, it is in some cases preferable to coat the inner walls of the trough **5** with a substance adhesively incompatible with the casting resin in order to prevent the resin, when hardened, from excessively adhering to the trough material. For example, when using the above-mentioned synthetic plastic on epoxy basis mixed with a suitable hardener, it is preferable to previously coat the inner wall of the entire mold with silicone fat.

It is further of advantage in some cases, before filling the synthetic plastic mass into the trough, to heat the trough-shaped mold together with the mounted rod to elevated temperature. For example, when using the above-mentioned epoxy resin "Araldite," the mold is preferably heated to a temperature of about 100° C. As

a result, the casting resin, after being filled into the mold, is first converted to a more thinly liquid condition due to the heat of the mold, and thus adapts itself more readily and completely to the irregular surface of the semiconductor rod. The preheating also has the effect that any air bubbles contained in the plastic mass can more readily escape upwardly out of the liquid level. Although the heating of the mass may accelerate hardening of the synthetic mass, this is in most cases desirable because it shortens the manufacturing time and makes the jacket-molding device more rapidly available for use with another semiconductor rod. Thus, when using "Araldite" in a mold preheated to about 100° C., complete hardening is obtained within about one hour.

After hardening of the plastic, the semiconductor body **1** with its jacket **12a** is taken out of the mold. To facilitate removal, the trough space of the mold is preferably given an upwardly widening shape. The jacketed semiconductor rod is then placed between the centering tapers **13** and **14** of a lathe as shown in FIG. 3. The conical ends of the bores, resulting in the jacket from the previous presence of the conical neck portions **8'**, **9'**, are adapted to the conical tips of the center tapers, so that a smooth, running fit is obtained. The peripheral surface of the plastic jacket is then machined down to the desired accurate diameter D corresponding to the inner diameter of the chuck **15** (FIG. 4) to be used in the subsequent slicing operation. As shown in FIG. 3, the machining is effected by means of a tool **15** starting from the right of the plastic jacket. The left-hand end **12a** of the jacket can be used for attaching thereto an entrainer which causes the jacketed body to turn about its axis during machining operation.

After the jacketed rod is completely machined down to diameter D, the rod is taken out of the lathe. The left-hand end **12a** (FIG. 3), previously required for entrainment, is no longer of any use and is sawed off. Then the rod is transferred to the slicing device schematically shown in FIG. 4. This device operates to cut the jacketed rod into individual semiconductor wafers of desired thickness. First, however, a disc of greater thickness is sliced off in order to obtain a definite planar end surface which later forms one of the ultimate surfaces of the first useful semiconductor wafer to be produced. The slicing device according to FIG. 4 comprises the above-mentioned chuck **15**. The jacketed rod **1** is pushed from the right through the chuck against an adjusted fixed stop **16**. This is done by a feeder device which only a pusher **19** is shown. Pusher **19** presses continuously against the right-hand end of the jacketed rod.

After the rod is thus pushed through the open chuck **15** against stop **16**, the chuck **15** is closed and the cutting tool is operated to slice a semiconductor wafer of the desired thickness from the rod. The slicing tool comprises a hub portion **17** and a circular diamond cutting disc **18**. The rotating cutting tool **18** passes from above through the jacketed rod. When a slice is completely removed, the tool moves upwardly away from the rod, the chuck **15** opens, and the pusher **19**, which may be biased toward the left by spring force, can now displace the jacketed body **1** toward the left until the rod again abuts against the stop **16**, whereafter the slicing operation is repeated.

As is apparent from FIG. 2, the auxiliary mold **4** is given greater axial length than would be necessary for producing upon and around the rod material, a jacket of synthetic plastic accurately corresponding to the length of the semiconductor rod. In this manner, the jacket comprises body portions that protrude axially beyond the end faces of the semiconductor rod and which are used to advantage during the subsequent processing. Thus, as mentioned, the portion **12a** (FIG. 3) of the plastic jacket of the lefthand end can be used for attaching thereto a clamping device or entrainer of a lathe which cooperates with the rotating drive of the lathe in order to keep the workpiece in rotation during machining. The body of resinous plastic protruding from the right end of the semiconductor rod can be utilized in an equally advantageous manner. As shown in FIG. 4, the latter portion of the plastic jacket forms the ultimate end of the workpiece that passes through the clamping chuck **15** of the slicing machine and thus makes it possible to cut semiconductor wafers from the rod up to complete consumption of the rod.

The slice produced in the above-described manner comprises a semiconductor disc **1***a* which is originally enclosed by a ring **12***a'* of synthetic material as shown in FIGS. 5 and 6. As described, the ring **12***a'* can readily be separated from the disc **1***a*, the ring and disc being separately shown in FIGS. 7 and 8 respectively. In order to separate the ring from the disc, the composite wafer according to FIGS. 5, 6 is either placed in a bath which causes swelling of the ring **12***a*, or the ring **12***a'* is simply bent out of the plane of the disc **1***a*, thus permitting a mechanical separation.

I claim:

1. The method of producing semiconductor wafers from rod-shaped monocrystalline semiconductor raw material such as germanium or silicon, which comprises forming indentations in the end faces of the raw semiconductor rod for defining a machining axis passing through said indentations, supporting said rod at said indentations while intimately joining with the semiconductor rod a jacket material along at least a major portion of the rod periphery and extending beyond said end faces so as to form a support during machining, machining the surface of said jacket material about said machining axis, clamping the machined surface, and slicing the rod together with the jacket material during said clamping, said jacket material forming the last portion of the slicing cut and having sufficient strength for bracing the semiconductor wafers being severed so as to prevent said wafers from cracking or breaking off from the semiconductor rod.

2. The method of producing semiconductor wafers from rod-shaped monocrystalline semiconductor raw material such as germanium or silicon, which comprises forming identations in the end faces of the raw semiconductor rod for defining a machining axis passing through said indentations, supporting rod at said indentations while enclosing the monocrystalline semiconductor rod over its entire periphery in a jacket of subsequently removable material, said jacket material defining portions extending beyond each end of the semiconductor rod to form a support during machining, forming coaxially aligned openings in said portions in alignment with said indentations and with said machining axis, machining the surface of said jacket material in a predetermined relationship relative to said machining axis, incrementally moving the jacket material with said rod embedded therein in the direction of said axis, clamping the machined surface, and transversely slicing the jacketed rod during said clamping, said jacket material forming the last portion of each slicing cut for bracing the semiconductor wafers being severed to prevent said wafers from cracking or breaking off from the semiconductor rod.

3. The method of producing semiconductor wafers from rod-shaped monocrystalline semiconductor material such as germanium or silicon, which comprises forming indentations in the end faces of the raw semiconductor rod for defining a machining axis passing through said indentations, supporting said rod at said indentations while embedding the semiconductor rod in a jacket of synthetic plastic material to form a support during machining, machining the surface of said jacket material about said machining axis, clamping the machined surface, during said clamping slicing the jacketed rod with said jacket material forming the last portion of each slicing cut, and removing the jacket material from each resulting semiconductor wafer.

4. The method of producing semiconductor wafers from rod-shaped monocrystalline semiconductor material such as germanium or silicon, which comprises forming indentations in the end faces of the raw semiconductor rod for defining a machining axis passing through said indentations, placing the monocrystalline semiconductor rod in a mold and supporting said rod at said indentations while embedding it within the mold in casting resin to produce a bracing jacket on the rod, machining the jacketed rod about said axis to obtain a given uniform diameter, advancing the machined rod incrementally along said axis through and relative to a holder conforming to said uniform diameter, and transversely slicing the jacketed rod.

5. The method of producing semiconductor wafers from rod-shaped monocrystalline semiconductor material such as germanium or silicon, which comprises forming indentations at desired locations in both ends of the rod to thereby secure in a desired position a processing axis through said indentations at the respective rod ends, mounting the rod at said ends in a mold and supporting said rod at said indentations while molding a bracing jacket onto the rod in concentric relation to said axis, removing the jacketed rod from the mold, machining the jacketed rod about said axis, moving the jacketed rod stepwise in the direction of said axis, clamping the machined jacketed rod and during said clamping transversely slicing the jacketed rod with said jacket material forming the last portion of each slicing cut for bracing the semiconductor wafers being severed to prevent them from breaking off the rod.

6. The method of producing semiconductor wafers from rod-shaped monocrystalline semiconductor material such as germanium or silicon, which comprises embedding the monocrystalline semiconductor rod in jacket of resinous material, peripherally machining the jacketed rod about a predetermined axis to obtain a surface concentric with said axis, advancing the machined rod incrementally along said axis, clamping the machined jacketed rod and during said clamping, slicing the jacketed rod with said jacket material forming the last portion of each slicing cut, and immersing the resulting slices in a liquid reactive agent toward said resinous material for facilitating removal of said material from each semiconductor wafer.

7. The method of producing semiconductor wafers from rod-shaped monocrystalline semiconductor material such as germanium or silicon, which comprises enclosing the monocrystalline semiconductor rod in jacket of resinous materal, peripherally machining the jacketed rod about a predetermined axis to obtain a surface concentric with said axis, advancing the machined rod incrementally along said axis, clamping the machined jacketed rod and during said clamping, slicing the jacketed rod with said resinous material forming the last portion of each slicing cut to prevent the semiconductor slice from breaking off the rod, and immersing the jacketed slices in a bath of solvent to remove the resinous material from the remaining semiconductor wafer.

8. The method of producing semiconductor discs from irregularly shaped raw bodies of monocrystalline semiconducting material, such as germanium and silicon, comprising the steps of embedding the raw monocrystalline body within a block of resinous plastic material, said block extending longitudinally at least to span the distance between the ends of said body to form a support during machining, forming center indentations at desired locations in said ends to define a machining axis for said body through said indentations, supporting said block by said indentations and then machining the block down into a regular shape of predetermined standard dimensions, thereafter clamping the machined shape in a holding device adapted to said predetermined shape and standard dimensions, and during said clamping slicing said body and said plastic material surrounding it into wafers of predetermined thickness.

9. The method according to claim 4, including the step of coating the inner walls of said mold with a substance adhesively incompatible with the casting resin to prevent

the resin after hardening from adhering to the walls of the mold.

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