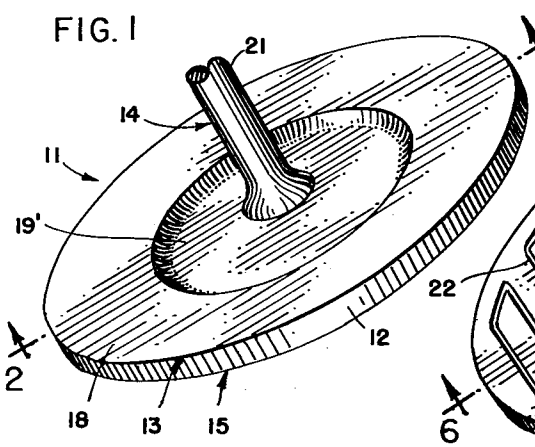
Nov. 6, 1962 B. ROSS 3,062,690

SEMI-CONDUCTOR DEVICE AND METHOD OF MAKING THE SAME

Filed Aug. 5, 1955

FIG. 1



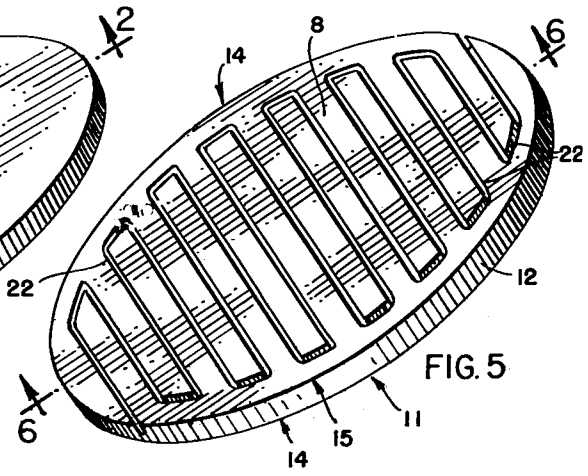


FIG. 5

FIG. 2

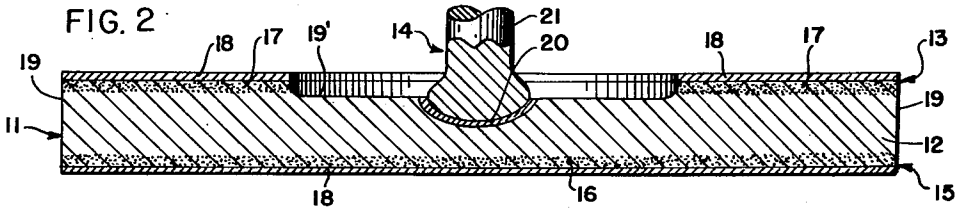


FIG. 3

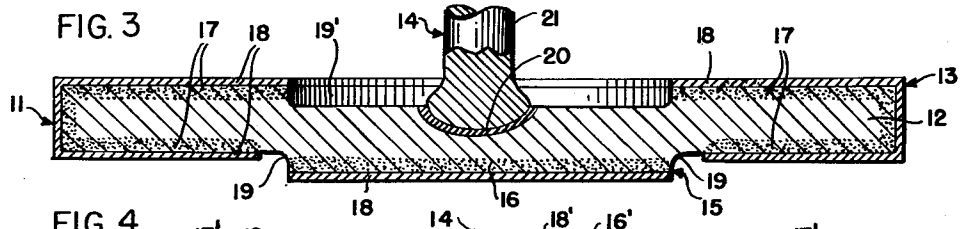
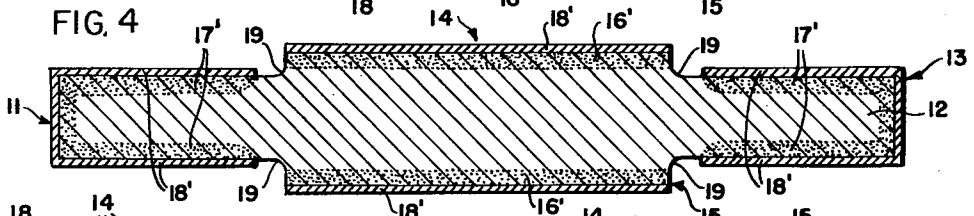


FIG. 4



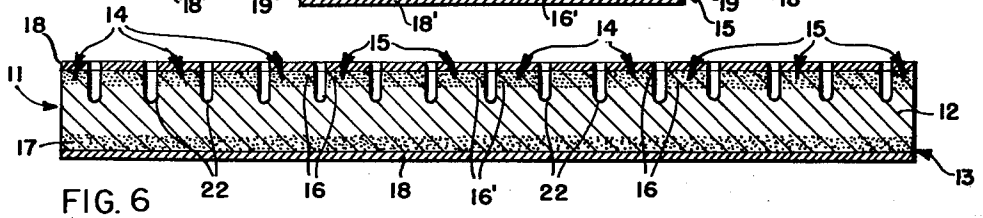


FIG. 6

INVENTOR:—

BERND ROSS

BY:—

Marzall, Johnston, Cook & Root

ATTORNEYS

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SEMI-CONDUCTOR DEVICE AND METHOD OF MAKING THE SAME

Bernd Ross, Chicago, Ill., assignor to Hoffman Electronics Corporation, Los Angeles, Calif., a corporation of California

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1 Claim. (Cl. 148—1.5)

The present invention relates in general to electronics and has more particular reference to electron flow devices, such as transistors, comprising semi-conductor material.

A semi-conductor material may comprise an intrinsic or pure substance, such as crystalline germanium, silicon or other suitable material, in which the valence ring electrons of the constituent atoms are tightly bound and hence unavailable for electrical conduction, the intrinsic material being doped or contaminated with an activating substance comprising atoms distributed in and forming an integral part of the lattice structure of the intrinsic material. The proportion of activating impurity to intrinsic material may be of the order of one impurity atom for each hundred million atoms of intrinsic material.

Suitable activating substances for activating intrinsic semi-conductor material comprise atoms containing either a greater or lesser number of valence electrons than the constituent atoms of the intrinsic material. Where the atoms of the activating substance comprise more valence electrons than are associated with the atoms of the intrinsic material, the excess electrons may circulate freely in and through the crystal structure of the semi-conductor material and are hence available for electrical conduction purposes. Activating substances which provide excess electrons are commonly referred to as electron donors since they supply electrons which are free to move within the lattice structure of the semi-conductor material. Excess electron semi-conductors are commonly referred to as comprising N-type material since electrical conduction is carried on by the flow of negatively charged electrons through the material.

Where the atoms of the activating substance embody fewer valence electrons than are associated with the atoms of the intrinsic substance, each atom of activating material must borrow electrons from an adjacent atom of the intrinsic material, thereby creating what may be referred to as a hole; that is to say, an imcomplete group of atom bonding electrons simulating the properties of a positively charged electron in the lattice structure of the semi-conductor material. Hole creating activators are commonly called acceptor materials since they take up electrons from the surrounding atoms of the intrinsic material to form positive holes therein. Intrinsic material activated by an acceptor substance is commonly referred to as a P-type semi-conductor since conduction therein is effected by the movement of positive holes in the material.

Electrical energy may flow in either direction through both types of semi-conductor material. When, however, a body of P-type material is joined with a body of N-type material to form therebetween what is commonly referred to as a P-N junction, the positive holes in the P-type material and the free electrons in the N-type material are mutually repelled away from the junction, thereby constituting the junction as a potential hill, past which electrical energy may flow more easily in one direction than the other. Accordingly, a semi-conductor element embodying a P-N junction may be employed as an electrical current rectifying device.

Heretofore semi-conductor elements embodying P-N junctions have been produced by initially growing a crystal ingot of intrinsic material to desired size in the presence of an activator of one kind, an electron donor material, for example, to thereby constitute the resulting crystalline substance as N-type semi-conductor material. Thereafter growth of the crystal ingot may be continued in the presence of an activating substance of the other kind, such as electron acceptor material, to thereby constitute subsequently grown portions of the ingot as P-type material. In such an ingot, the P-N junction extends between the N-type and P-type portions of the ingot body.

An important object of the present invention is to provide a semi-conductor device comprising a body of crystalline material in which an activating substance has been incorporated entirely after the formation of the crystalline material body.

Another important object is to provide a semi-conductor device by first forming an ingot of crystalline material as by growing the same under controlled conditions, cutting discs or plates of desired size from the ingot and thereafter exposing surface portions of the plates to an activating substance in vaporized condition.

Another important object is to provide a semi-conductor device by first forming a body of crystalline material of desired configuration, thereafter exposing the body in an atmosphere comprising a vaporized activating substance of one type, to obtain penetration of such substance to a desired depth at and beneath the surfaces of said body, thereafter removing surface portions of said body to a depth greater than the penetration of the activating substance, to thereby expose material of the body to which said activating substance has not penetrated, and thereafter applying a vaporized activating medium of another type to the exposed portions of said body to obtain penetration thereof by said other activating substance to a desired depth.

Another important object is to provide a semi-conductor device by first forming a body of crystalline material of desired configuration, thereafter exposing the body in an atmosphere comprising a vaporized activating substance of one type, to obtain penetration of such substance to a desired depth at and beneath the surfaces of said body, thereafter removing surface portions of said body to a depth greater than the penetration of the activating substance, to provide a station for the attachment of a connection conductor with material of said body to which said activating substance has not penetrated.

Another important object resides in providing a semi-conductor device comprising a body of crystalline material of selected type having a surface thereof doped with an activating substance to a desired depth in order to constitute such doped portions of the body as semi-conductor material of the other type, thereby establishing a P-N junction between the doped portions and the remaining portions of said body.

Another important object is to provide a semi-conductor device comprising a relatively thin plate of crystalline material, such as silicon, containing an activating substance, constituting the plate as a semi-conductor of desired type, the plate having a surface portion doped

with a different activating substance to a desired depth, as by exposure of said surface portions to the activating substance in vaporized condition during a selected interval, to thereby constitute the doped portions of the plate as semi-conductor material of type other than that constituting the remaining portions of the plate.

Another important object is to provide a semi-conductor device comprising a plate of crystalline semi-conductor material having means formed on a surface portion of the plate to provide a transistor base, said plate having another surface portion coated with a layer of material having characteristics different from the remaining portions of the plate, said other surface being formed with a continuous groove therein and extending from one side of the plate to the other, said groove extending through said layer and into the body of the plate therebeneath to separate the layer on opposite sides of the groove and to constitute the separated portions of the layer, respectively, as a transistor emitter and a transistor collector.

The foregoing and numerous other important objects, advantages and inherent functions of the invention will become apparent as the same is more fully understood from the following description, which, taken in connection with the accompanying drawings, discloses preferred embodiments of the invention.

Referring to the drawings:

FIG. 1 is a perspective view showing a semi-conductor device embodying the present invention;

FIG. 2 is a setcional view taken substantially along the line 2—2 in FIG. 1;

FIGS. 3 and 4 are similar sectional views taken through modified devices embodying the invention;

FIG. 5 is a perspective view of another modified device embodying the invention; and

FIG. 6 is a sectional view taken substantially along the line 6—6 in FIG. 5.

To illustrate the invention, the drawings show semi-conductor devices **11** forming transistors, each consisting of a body **12** of crystalline semi-conductor material and means formed on and operatively associated with the body **12** to provide a transistor base **13**, and connection means **14** and **15**, either of which may serve as the emitter element of the transistor while the other is serving as the collector element thereof.

The body **12** may comprise any suitable semi-conductor material, such as silicon, containing a selected activating substance distributed through the lattice structure of the material in order to provide desired semi-conductor characteristics. Atomic quantities of the activating substance may be distributed throughout the material of the body **12** in proportions of the order of one atom of activating substance for every one hundred million atoms of the intrinsic material of the body **12**. Arsenic, antimony or other suitable electron donor material may thus be employed as an activating substance to constitute the body **12** as an N-type semi-conductor, while boron, indium or other suitable acceptor material may be employed as an activating substance if it be desired to constitute the body **12** as a P-type semi-conductor.

The body **12** preferably comprises a relatively thin disc or plate, which may be cut from a crystalline ingot of the selected semi-conductor material containing a desired activating substance. Portions **16** of the plate, at and inwardly of a surface thereof, may be treated with an activating substance other than and different from that distributed in the body **12** of the disc in order to alter the type of the semi-conductor material at and to a desired depth inwardly of the bounding surface of the treated portions **16**. Where the disc comprises N-type semi-conductor material, the portions **16** may be treated with boron, aluminum, indium or other electron acceptor substance in order to constitute the plate portions **16** as P-type semi-conductor material. Conversely, where the disc comprises P-type semi-conductor material, the portions **16** may be treated with arsenic, antimony or other electron donor substance in order to constitute the plate portions **16** as N-type semi-conductor material. Preferably, the plate **12** comprises N-type silicon material embodying arsenic or antimony as the activating substance, the surface portions **16** being treated with boron in order to constitute the same as P-type semi-conductor material.

The activating substance employed to determine the character of the material in the portions **16** may be applied to the surface of the plate and caused to penetrate to a desired depth in said portions by exposing the plate **12** in an atmosphere consisting of the activating substance in vaporized condition, the plate **12** being retained in such atmosphere during a period sufficient to obtain penetration of the activating substance to a desired depth at and beneath the surface of the plate. Any suitable, preferred or convenient means may be employed to prevent the application of the activating substance to surfaces other than those at which penetration of the substance is desired. It is, however, preferable to expose the entire plate **12** to the vaporized activating substance so that penetration of the activator is obtained at all exposed surfaces of the plate. Thereafter the plate may be ground, milled or etched in order to remove all portions of the plate penetrated by the activating substance except those portions **16** which it is desired to retain. It will be apparent, of course, that a P-N junction will thus be established between the boundary of the activated portions **16** and the remaining portions of the plate **12**.

After formation of the activated surface portions **16**, the plate **12**, if it comprises N-type semi-conductor material, may be exposed to the action of vaporized phosphorus or other especially active electron donor material in order to constitute the remaining surface portions **17** of the plate **12**, other than the portions **16**, as N+ type semi-conductor material, to a desired depth in said other surface portions. Where the constituent material of the plate **12** comprises P-type semi-conductor material, the plate should, of course, be treated with an especially active electron acceptor substance in order to form P+ type material in the plate portions **17**. It will of course be realized that the N+ or P+ (as the case may be) surface portions **17** are more heavily doped than the central portion of plate **12**, and that surface portions **17** in being heavily doped serve merely as bonding layers or portions to accommodate the affixing thereto of those layers **18**, hereinafter mentioned, which constitute base electrodes. After the character of the material in the plate portions **17** has been established to desired depth, portions of the plate may be removed, as by grinding, milling or etching, as indicated at **19**, in order to isolate the activated material comprising portions **17** from the material constituting the portions **16**. Exposure of previously treated portions **16** to vapors of the substance employed to activate the portions **17** will not materially alter the character of the portions **16**. If desired, the exposed boundary surfaces of the portions **16** may be coated or otherwise masked by a layer of material that is impervious to the activating substance, during exposure of the portions **17** to the activating substance.

In order to protect and also to provide for electrical connection of the activated plate portions **16** and **17** in external electrical circuits, said surfaces may be provided with coating layers **18** of nickel, which may be applied in any suitable or convenient fashion, as by electrodeposition of the layers or by condensing the layers upon the surfaces to be coated from a vaporized atmosphere of the coating metal. The application of such a layer to the surface of the portions **16**, prior to the application of an activating substance to the portions **17**, will, of course, preclude any contamination of the portions **16** by the activating substance applied to the portions **17**.

In the embodiment illustrated in FIGS. 1 and 2 of the drawings, a surface portion of the plate **12** may be etched

out, as with acid, in order to provide a shallow depression 19' disposed preferably centrally of the plate 12 upon the face thereof containing the activated portions 17, the bottom of the depression 19' extending beneath the depth of penetration of the activating material to thereby reveal and expose material of the plate 12 which is entirely free of the activating substance in the plate portions 17. A suitable etching medium for such purpose may comprise a mixture of nitric and hydrofluoric acids.

As shown more particularly in FIGS. 1 and 2, the connection means 14 of semi-conductor devices embodying the present invention may comprise an alloyed P-N junction 20 in addition to the doped P-N junction formed between the constituent material of the plate portions 16 and the remaining portions of the plate. Where plate 12 is initially N-type material, this alloyed junction comprises a length of aluminum wire 21 having an end penetrating into and alloyed with the material of the plate 12, preferably centrally of the depression 19', such junction being formed by heating the plate 12 and the aluminum wire 21 to a temperature of the order of, but somewhat less than, their melting temperatures, and then pressing the end of the wire upon and into the plate to a selected depth at the place where the junction is desired. As the end of the aluminum wire becomes alloyed with the material of the plate, it will spread and expand to a limited extent, as shown in FIGS. 1 and 2, and the alloyed junction will be formed between the plate and wire, said junction comprising recrystallized material of the plate containing aluminum dispersed therein. Where plate 12 is initially P-type material, wire 21 will comprise donor or N-type material.

The foregoing procedure for the fabrication of transistors allows for every precise control of the spacement of collector, base and emitter. Such control may be accomplished by regulating the time intervals during which, and the temperature at which, the plate 12 is exposed to the vaporized activating substances in doping the plate portions 16 and 17. If a device should be unsatisfactory due to improper spacing of emitter and collector, the device may be retreated and the wire 21 embedded more deeply in the plate 12. The ability to thus easily control spacements makes it possible to readily attain, in each transistor, precise characteristics selected from a wider range thereof.

In FIGURE 3 a transistor device is shown which is similar to that of FIGURES 1 and 2. However, in the case of FIGURE 3 the base electrode 18 is seen to extend not only on the top surface of plate 12 but also on the edge surface and on a portion of the lower surface thereof. The emitter (or collector) electrode layer 18 which is affixed to the surface of semiconductor portion 16 is physically separated from electrode layer 18 and semiconductor portion 17 by relief area 19.

The device of FIGURE 3 may be fabricated as follows. A disc of semi-conductor material may be doped with activating material at the lower surface thereof to provide activated layer 16. The remaining portions of the disc may be masked during this initial operation. Then the disc may be ground, etched or milled on the lower surface to remove the peripheral portions of the activated zone 16 and leave only the central portion of the disc. The disc may then be doped with activating material of desired character to a desired depth to provide an activated portion 17. During this operation the previously doped portion may or may not be masked, as desired. Finally, the ground, milled, or etched relief areas 19 and 19' may be provided (the latter to separate activated zones or portions 16 and 17) and the electrode layers 18 and wire 21 affixed in the same manner as that above described.

A modified form of device embodying the invention is shown in FIG. 4, wherein the connection means 14 comprises a doped junction similar to the connection means 15. In producing the device shown in FIG. 4, a disc of material may be doped with activating material

to desired depth to provide activated zones or layers 16 on each of its opposite sides. The disc may then be ground, etched or milled on both sides to remove the peripheral portions of the activated zones 16 and leave only the portions of said zones which extend at the medial portions of the disc. The disc may then be doped with activating material of desired character, to a desired depth to provide an activated zone or layer 17 in the peripheral portions of the disc.

The surfaces of the disc may then be electroplated or otherwise coated with nickel or other electrical conducting material to provide an electrical conducting layer 18 on said surfaces. This layer and the body of the disc, between the zones 16 and 17 may then be cut away as at 19. If desired, the disc may be coated with a layer of conducting material after the formation of the activated zones 16 and before the removal of the peripheral portions thereof, to thereby minimize the possibility of contaminating the material of the zones 16 with the substance used subsequently to activate the zone 17.

Another form of device embodying the invention is shown in FIGS. 5 and 6, said device comprising a disc of semi-conductor material 12 containing doped layers 16 and 17 of material of unlike electron flow promoting character on the opposite sides of the disc, a conducting layer 18 of nickel or other electrical conducting material being coated, as by electrodeposition or otherwise, upon the surfaces of the layers 16 and 17 to facilitate electrical contact therewith. In this arrangement the layer 17 and its coating 18 may constitute a transistor base, while the layer 16 may be intersected by a groove 22 extending from one side of the disc to the other, in order to separate the layer 16 and its overlying conductive coating 18 into emitter and collector portions 14 and 15 on opposite sides of the groove. The groove, throughout its length, extends entirely through the layer 16 and its surface coating 18, and into the material of the disc 12, inwardly of the layer 16. The groove is preferably of serpentine character, as shown. It may, however, conveniently be formed to extend diametrically straight across the disc; or it may have any other preferred layer separating configuration.

It is thought that the invention and its numerous attendant advantages will be fully understood from the foregoing description, and it is obvious that numerous changes may be made in the form, construction and arrangement of the several parts without departing from the spirit or scope of the invention, or sacrificing any of its attendant advantages, the forms herein disclosed being preferred embodiments for the purpose of illustrating the invention.

The invention is claimed as follows:

The method of making an electron flow device which comprises forming a disc of crystalline semiconductor material exhibiting an intrinsic electrical characteristic, said disc having first and second opposing surfaces, exposing said disc to a first activating substance in vaporized condition to obtain atomic penetration for a desired depth by said substance of the material of said disc, at and inwardly of said first surface thereo, said first activating substance exhibiting an electrical character opposite to the intrinsic electrical characteristic of said disc, exposing said disc to a second activating substance in vaporized condition to obtain atomic penetration for a desired depth by said second substance of the material of said disc, at and inwardly of said second surface thereof, said second activating substance exhibiting an electrical character similar to the intrinsic electrical characteristic of said disc, bonding to each of said first and second surfaces of said disc first and second respective layers of low resistance metallic substance, thereafter removing atomically penetrated portions in the central portion associated with said first surface of said disc, together with the portion of the metallic layer disposed thereover, to leave an integral layer of atomically pene-

trated material encircling said central portion of said disc, and then fusing a conductor of electrical character opposite to the electrical characteristic of said second activating substance to the uncovered portion of said disc.

References Cited in the file of this patent

UNITED STATES PATENTS

2,629,800	Pearson	Feb. 24, 1953
2,644,852	Dunlap	July 7, 1953
2,689,930	Hall	Sept. 21, 1954
2,721,965	Hall	Oct. 25, 1955
2,725,315	Fuller	Nov. 29, 1955
2,757,323	Jordan et al.	July 31, 1956
2,742,383	Barnes et al.	Apr. 17, 1956
2,770,761	Pfann	Nov. 13, 1956
2,778,980	Hall	Jan. 22, 1957
2,804,405	Derick et al.	Aug. 27, 1957
2,837,704	Emeis	June 3, 1958

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,062,690 November 6, 1962

Bernd Ross

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 3, line 31, for "setcional" read -- sectional --; column 5, line 34, for "every" read -- very --; column 6, line 60, for "thereo" read -- thereof --.

Signed and sealed this 28th day of May 1963.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents