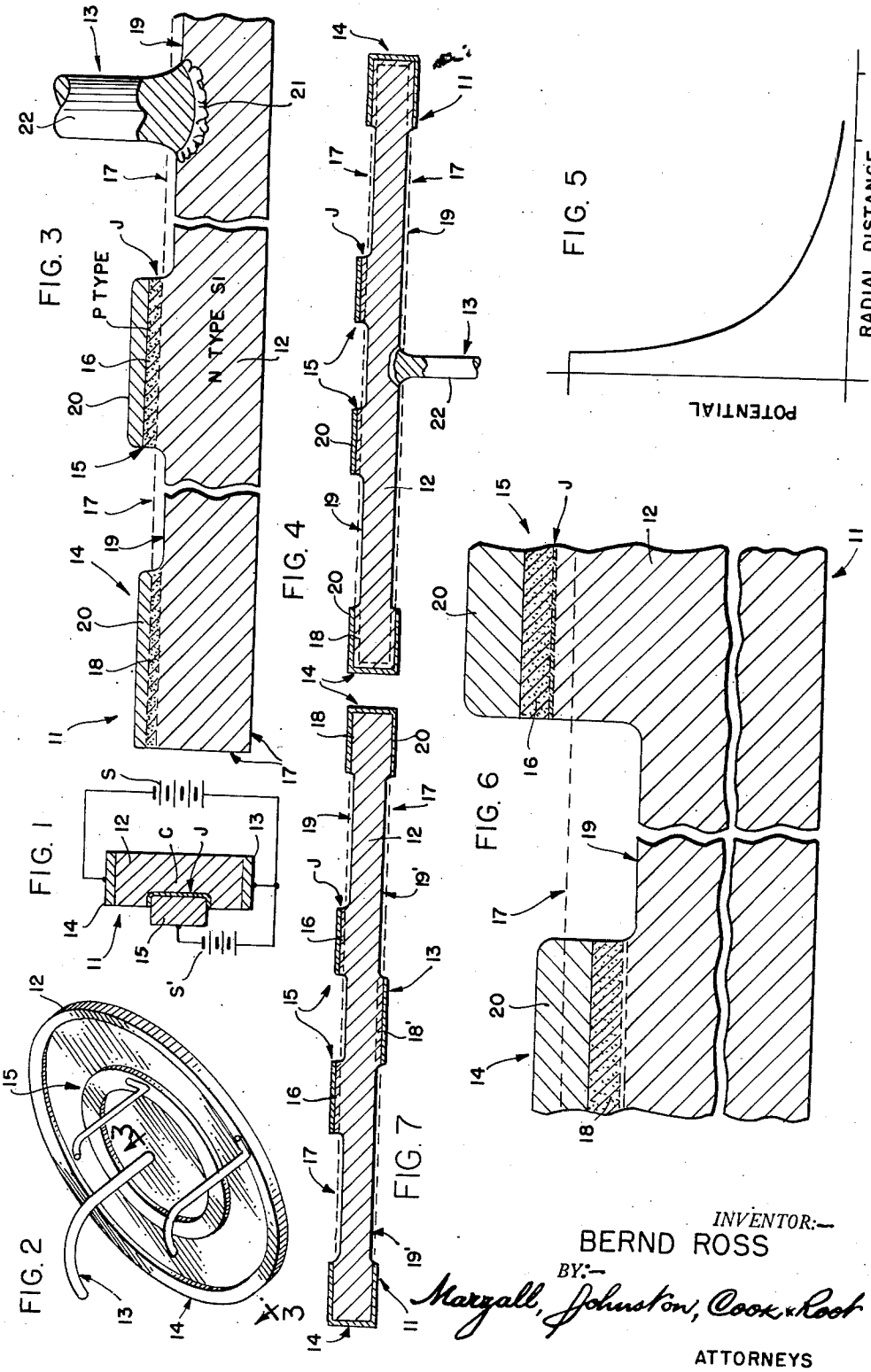
June 12, 1962

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3,039,028

DOUBLE BASED DIODE

Filed Sept. 26, 1955



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United States Patent Office 3,039,028 Patented June 12, 1962

3,039,028

DOUBLE BASED DIODE

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Filed Sept. 26, 1955, Ser. No. 536,536
2 Claims. (Cl. 317—234)

The present invention relates in general to electronics and has more particular reference to electron flow devices employing semi-conductor material, the invention pertaining specifically to an improved double based diode and method of making the same.

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 incomplete 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. In this connection, the P-N junction is the equivalent of a unidirectional potential source having a negative side and positive sides respectively connected with the P-type and N-type materials on opposite sides of the junction, thereby constituting the junction as a potential hill, past which electrical energy may flow more easily in one direction than the other. If, for example, the opposite positive and negative sides of a source of unidirectional

electrical potential be connected respectively with the N-type and P-type ends of a P-N junction element, in fashion commonly referred to as reverse bias, such potential source will merely increase the potential hill, by drawing the valence electrons and holes mutually away from the junction, and, consequently no current flow may take place across the P-N junction. On the other hand, connection of the positive and negative sides of a source of unidirectional electrical potential, as a so-called forward bias, respectively to the P-type and N-type ends of a P-N junction element, will tend to offset the potential hill by driving the holes of the P-type material and the electrons of the N-type material toward the junction, thereby allowing current flow across the junction if and when the applied potential exceeds the potential drop across the junction element, including the equivalent potential value of the junction hill. Accordingly, a semi-conductor element embodying a P-N junction may be employed as an electrical power rectifier.

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 an electron acceptor material, to thereby constitute the 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.

A so-called double based diode may comprise bodies of P-type and N-type material inter-connected by means of a P-N junction, provision being made for the ohmic connection of one of said bodies in an external circuit at spaced apart contact stations, called bases, on said body, and for the ohmic contact of the other of said bodies in external circuitry, in order that the device may function in desired fashion as hereinafter described.

An important object of the present invention is to provide for the formation of a semi-conductor device of the character mentioned by applying, to a body of material of selected type, an activating substance in vaporized condition whereby to activate or condition portions of said body at and inwardly of a surface thereof as material of another type, whereby to form a P-N junction between the so conditioned surface portions of the body and the portions thereof lying inwardly of said surface portions; a further object being to form the body as a disc or plate and to activate surface portions of the plate; a still further object being to dispose the activated portions in centered relation in the disc or plate; yet another object being to form the activated portions as a ring-like zone on the disc.

Another important object is to provide a device of the character mentioned by first forming an ingot of crystalline semi-conductor material, as by growing the same under controlled conditions, thereafter cutting discs or plates of desired thickness from the ingot, then exposing such plates to an activating substance in vaporized condition to obtain atomic penetration of the substance within the material of the plate at and inwardly of a surface thereof, to thereby produce a P-N junction within the body of the plate between such substance penetrated portions of the plate and the plate material inwardly of said portions.

Another important object is to provide a device of the character mentioned by first forming a body of crystalline semi-conductor material of desired configuration and selected type and thereafter exposing the body in an atmosphere comprising a vaporized activating substance

of another type, to obtain penetration of such substance to a desired depth beneath the exposed surface of said body to thereby form a P-N junction between the so penetrated portions of said body and the material thereof inwardly of such penetrated portions, thereafter removing some of the so penetrated portions to thereby retain only desired parts on zones thereof on the body, while exposing material of the body to which the activating substance has not penetrated, in order to define the marginal edges of said zones, and also to permit ohmic contact with said unpenetrated body portions at contact stations spaced from the P-N junction.

Another important object is to provide an ohmic contact on a device of the character mentioned embodying integrated body portions providing a P-N junction therebetween, by exposing the device in an atmosphere comprising a vaporized conditioning substance to obtain penetration thereof to a desired depth at and beneath the surfaces of at least one of said body portions to thereby provide ohmic contact therewith, thereafter removing some of the so penetrated surface portions to a depth greater than the penetration of the conditioning substance whereby to isolate and localize the zone of ohmic contact.

Another important object is to provide a semi-conductor device of the character mentioned by first forming a body of crystalline material doped with activating material of desired type, thereafter exposing the body in an atmosphere comprising a vaporized activating substance of another type, to obtain penetration of such substance to a desired depth, at and beneath the surface of said body, and to produce a P-N junction between the penetrated and impenetrated portions of said body, thereafter removing surface portions of the body to a depth greater than the penetration of such activating substance, to thereby define the marginal edges of an activated zone in said body, and to expose body material, around said zone, to which the activating substance has not penetrated, and by thereafter applying a vaporized medium to such exposed body portions to provide an ohmic contact zone on said body.

Another important object is to provide a semi-conductor device of the character mentioned comprising body portions of material of unlike type providing a P-N junction therebetween, one of said bodies having an ohmic contact zone formed thereon remote from said junction and a metal wire integrally connected to said body and forming another ohmic contact zone remote from said junction; a further object being to apply the metal wire on the body by heating the same and the wire to a temperature approaching the melting temperatures of the material of the body and wire, and by thereafter pressing the wire into the body to a desired depth to thereby accurately determine the spacement between the embedded end of the wire and said P-N junction.

Another important object is to provide a semi-conductor device of the character mentioned comprising a relatively thin plate of material, such as silicon, containing an activating substance constituting the plate as a semi-conductor of desired type, means forming a body of material of different type on said plate to provide a P-N junction between said body and plate, and means forming ohmic contact with said plate comprising a wire of metal, such as gold, containing an activating substance to constitute the metal wire as material of type like that of the body, the wire at an end thereof being embedded in and thus integrally connected with the plate.

Another important object is to provide a semi-conductor device of the character mentioned comprising crystalline material, such as silicon, containing an activating substance to constitute 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 to constitute the doped portions of the plate as a semi-conductor of type different from that constituting the remaining portions of the plate; a further object being to form on said remaining portions of the plate a pair of ohmic contact zones or stations, constituting a pair of contact bases on said device.

Another important object is to provide a semi-conductor device of the character mentioned comprising a plate of silicon containing an activating substance to constitute the plate as an N-type semi-conductor, the plate having a surface portion doped with an activating substance such as boron to a desired depth inwardly of the surface to thereby constitute the doped portions of the plate as P-type semi-conductor material, the plate, remote from said doped portions, being treated as with excess electron donor material, such as phosphorus, to form an ohmic contact zone on the plate remote from said doped portion, as at the peripheral edges of said plate, and a wire of material such as gold, containing antimony or other suitable electron donor material atomically dispersed therein, said wire having an end integrally connected in said plate form ohmic contact therewith in position spaced from said doped portion.

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 purely diagrammatic illustration of a double based diode structure for the purpose of revealing the manner in which such devices are adapted to function;

FIG. 2 is a perspective view of a double based diode made in accordance with the teachings of the present invention;

FIG. 3 is an enlarged sectional view taken substantially along the line 3—3 of FIG. 2;

FIGS. 4 and 7 are sectional views taken through modified double based diodes made in accordance with the teachings of the present invention;

FIG. 5 is a graphical representation of the potential gradient which may be established radially outwardly in the diode shown in FIG. 4 when the same is in operation; and

FIG. 6 is a greatly enlarged sectional view showing portions of the device illustrated in FIG. 3.

To illustrate the invention, FIG. 1 of the drawings diagrammatically illustrates the functional parts of a double based diode **11**, the same comprising a body **12** of semi-conductor material of selected type, the body **12** being provided with ohmic contact means **13** and **14** forming spaced apart bases at the opposite ends of the body **12**. A conventional double based diode of the sort illustrated in FIG. 1 may also include a body portion **15** of material of type unlike that of the body **12**, the bodies **12** and **15** being integrally connected to form a P-N junction J therebetween.

By inter-connecting the bases **13** and **14** with a power source B such as a battery providing electrical potential of V volts, the potential at any zone or level such as the level C, in the body **12** between the bases **13** and **14**, will be proportional to the distance of such level from one of the bases, such as the base **13**, as compared with the distance between the bases, the material of the body **12** providing substantially uniform resistance between the bases. If it be assumed that the level C is precisely midway between the bases, then the electrical potential at the level C with respect to either base will be $V/2$. If an equivalent potential be applied between the base **13** and the body portion **15**, as by means of a power source S, the entire junction surface J, on the side thereof which faces the body portion **15** will be at potential $V/2$, while the potential on the opposite side of the junction will be equal to $V/2$ only at the level C. All portions of the junction J above the level C, on the side of the junction which faces the body **12**, will be at a potential greater than

$V/2$, while all portions of the junction below the level C, on the side of the junction which faces the body portion **12**, will be at a potential less than $V/2$. Accordingly the junction portions below the level C may be electrically biased in the forward direction so that electrical current will be urged to flow from the body portion **15** through the junction and into the body portion **12**. Above the level C, however, the junction will be electrically biased in a direction tending to cause current flow from the body **12** to the body portion **15**, but such current flow may not take place, because of the rectifying action of the diode structure at the P-N junction. Current flow through the junction below the level C may cause the emission of holes into the material of the body **12**, thereby lowering its resistance between the bases **13** and **14**. As a consequence, current flow through the body **12** between the bases **13** and **14**, under the influence of the battery B, will increase, thereby shifting the potential level C toward the base **14**. Accordingly, a larger junction area, beneath the so shifted level C, will be made available for current flow from the body **15** into the body **12**, thereby further reducing the resistance of the body **12** between the bases **13** and **14**. The foregoing shift in potential level on the side of the junction which faces the body **12** will continue until the potential level registers with that edge of the junction which is closest to the base **14**. The foregoing characteristic phenomenon constitutes the double based diode as the equivalent of a resistor having negative resistance characteristic since, without change in applied potential, current flow has increased.

The present invention has, for its important object, the provision of a double based diode of novel construction, the same, as shown, for example, in FIGS. 2, 3, 4, 6 and 7, preferably comprising a disc or plate of a suitable semi-conductor material, such as silicon, forming the body **12** of the diode, the material of the body containing a selected activating substance distributed through the lattice structure of the material in order to provide the body with desired semi-conductor characteristics. Atomic quantities of the activating substance may thus be distributed through the body **12** in the proportions of one atom of activating substance for every 100,000,000 atoms of its intrinsic material. Arsenic, antimony or other suitable electron donor material may thus be employed as an activating substance in order to constitute the material of the body **12** as N-type semi-conductor material, 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**, 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 plate which forms the body **12** 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 material of the body **12** 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 portions **16** as N-type semi-conductor material. Preferably, the body **12** comprises N-type silicon 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 therein by exposing the plate **12** in an atmosphere consisting of the activating substance in its vaporized condition, the plate **12** being retained in such atmosphere and hence soaked in the vaporized activating substance 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 other surface portions of the body **12** than those at which penetration of the activating substance is desired. It is, however, preferable to expose all plate surfaces 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, etched or otherwise worked or processed as at **17** in order to remove all surface portions of the plate that have been penetrated by the activating substance except those portions **16** which it is desired to retain. A suitable etching medium for such purpose may comprise a mixture of nitric and hydrofluoric acids. As shown, the present invention contemplates retention of a preferably ring-like zone forming the treated portions **16**, such zone being disposed concentrically in the disc forming the body **12**. If desired, however, the portions **16** may be formed as a plate-like zone, at the center of the disc, as distinguished from the ring-like zone configuration illustrated. It will be apparent, of course, that a P-N junction will be established between the activated portions **16** and the remaining or underlying portions of the body **12**.

After formation of the activated surface portions **16**, means may be formed on the body **12** to provide ohmically connected bases **13** and **14** thereon. To this end 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 **18** of the plate **12**, as for example, the surface portions disposed, in the plate, outwardly of the activated portions **16**, as N+ type semi-conductor material, to a desired depth. 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 **18**.

After the character of the material in the plate portions **18** has been established, to a desired depth, to form ohmic connection with the body portions of the plate **12**, the plate may be ground, milled, etched or otherwise worked or processed, as at **19**, in order to isolate the activated material comprising the portions **18** from the material constituting the portions **16**. As shown, the retained portions **18** may be of ring-like configuration and may be disposed at the marginal edge of the plate **12**, the inner edge of the retained portions **18** being equally spaced from the outer edge of the portions **16**. Exposure of previously treated portions **16** to vapors of the substance employed in activating the portions **18** will not materially alter the character of the portions **16**. If desired, however, the exposed surfaces of the portions **16** may be coated or otherwise masked by means of a layer of material which is impervious to the activating substance, during exposure of the portions **18** to said activating substance.

In order to protect and also to provide for electrical connection of the activated portions **16** and **18** in external electrical circuits, said surfaces may be provided with a coating of nickel **20**, which may be applied in any suitable or convenient fashion as by electro-deposition of the material, or by condensing it upon the surfaces to be coated from a vaporized atmosphere of the coating material. The application of such a coating layer to the surface of the portions **16**, prior to the application of an activating substance to the portions **18**, will, of course, preclude any contamination of the portions **16** by the substance applied to activate the portions **18**.

In the embodiments illustrated in FIGS. 2, 3 and 4, the base connection 13 may comprise an alloyed junction 21 formed by connecting a length of metal wire 22 doped with an activating substance to constitute the wire as material of the same type as that of the body 12. Where the body 12 comprises N-type silicon the wire 22 may comprise gold, or other suitable metal, doped with antimony or other preferred electron donor material. The wire 22 may be attached to the plate 12 by heating the plate and the wire to a temperature of the order of, but somewhat less than, their melting temperatures, and by then pressing the end of the wire upon and into the plate to a selected depth at the place where it is desired to form the junction. As the end of the wire becomes alloyed with the material of the plate, it will spread and expand to a limited extent, as shown, and the alloyed junction 21 of ohmic character will be formed between the plate and the wire, said junction comprising recrystallized material of the plate containing the material of the wire disposed therein. The connection wire 22 is preferably applied in position disposed concentrically with respect to the treated portion 16 so that the edge of the treated portion 16 and of the P-N junction J is substantially equidistant from the ohmic junction 21 in all direction radially of the wire 22. The wire 22 as shown in FIGS. 2 and 3 may be connected to the same side of the plate 12 upon which the portions 16 and 18 are formed. However, as shown in FIG. 4, the wire 22 may be attached to the side of the plate 12 opposite from that upon which the treated portions 16 are formed. It is also within the contemplation of the invention to apply a ring-like junction forming portion 16, an ohmic junction 18 and an ohmically connected wire 22, on both of the opposite sides of the plate.

As shown more particularly in FIGS. 4 and 7, the ohmic connection portions 18 which form the base 14, may extend peripherally of the plate 12 on both sides of and across the marginal edge of the plate, such arrangement being particularly desirable where the ohmic connection 13 is disposed on the side of the plate remote or opposite from the treated portions 16, or where a junction forming portion 16 and ohmic connection 13 are formed on each of the opposite sides of the plate. Furthermore, as shown more particularly in FIG. 7, the ohmically connected base 13 may comprise a body portion 18' of character identical to the body portions 18, the portions 18 and 18' being formed simultaneously in the surfaces on the plate 12 and being defined and separated by the removal, as at 19', of intervening treated portions of the plate 12.

In making the devices shown in FIGS. 2, 3, 4 and 7, the plate 12 may first be exposed to vaporized material for conditioning the portions 16. Activated surface portions of the plate may then be cut away as to the level 17 to remove all treated portions except those that it is desired to retain in the finished diode. Thereafter the plate may be exposed to the fumes of an activating substance for conditioning the plate portions 18 and 18'. The plate may then be coated as with nickel to form the layers 20, after which the material of the treated and coated plate may be cut away, as at 19, to leave only such portions of the layers 16, 18 and 20 as may be desired to retain. In the embodiment shown in FIG. 7 the portions 18 and 18' and their covering layers will be formed simultaneously in the diode. In forming the devices shown in FIGS. 2, 3 and 4, the wire 22 may be attached as the concluding step in the production of the diode.

The foregoing procedure for the fabrication of a double based diode allows for exceedingly precise control of the spacement of the ohmically connected bases 13 and 14 with respect to the P-N junction J. It also allows the area of the junction J to be controlled easily and with utmost precision. Diodes may be made in accordance with the present invention in any desired size limited only by mechanical ability to produce and work the plate 12 of intrinsic material. In that connection, diodes having a diameter of as little as ⅛ inch and as large as one inch and more are entirely feasible, the power transferring ability of the device, of course, being a function of its physical size.

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:

1. A semiconductor device comprising a body of semiconductor material of relatively thin flat shape presenting opposed major surfaces, a central ohmic contact zone on one of said surfaces, a rectifying junction contact of annular configuration on the other of said surfaces, disposed about and spaced in the axial direction away from said central contact zone but inwardly of the margins of said body, said rectifying junction contact forming a gate electrode contact, and a second ohmic contact zone constituted by contact material formed upon the peripheral margins of both said major surfaces of said body and extending integrally across the edge thereof; said two ohmic contact zones forming source and drain electrodes adapted for connection with an external load circuit for control of the current flow therein in accordance with the electric field established by said junction contact transversely of the internal load circuit between said ohmic contact zones.

2. A semiconductor device comprising a body of semiconductor material of relatively thin flat shape presenting opposed major surfaces, a central ohmic contact zone on one of said surfaces, a rectifying junction contact of annular configuration on the other of said surfaces, disposed about and spaced in the axial direction away from said central contact zone but inwardly of the margins of said body, said rectifying junction contact forming a gate electrode contact, said body additionally carrying ohmic contact material on the peripheral margins of both of said major surfaces of said body outwardly of said annular junction contact, and means electrically connecting the ohmic contact material on said peripheral margin portions to define therewith a second ohmic contact zone; said two ohmic contact zones forming source and drain electrodes adapted for connection with an external load circuit for control of the current flow therein accordance with the electric field established by said junction contact transversely of the internal load circuit between said ohmic contact zones.

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