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B. ROSS

2,919,386

RECTIFIER AND METHOD OF MAKING SAME

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FIG. 1

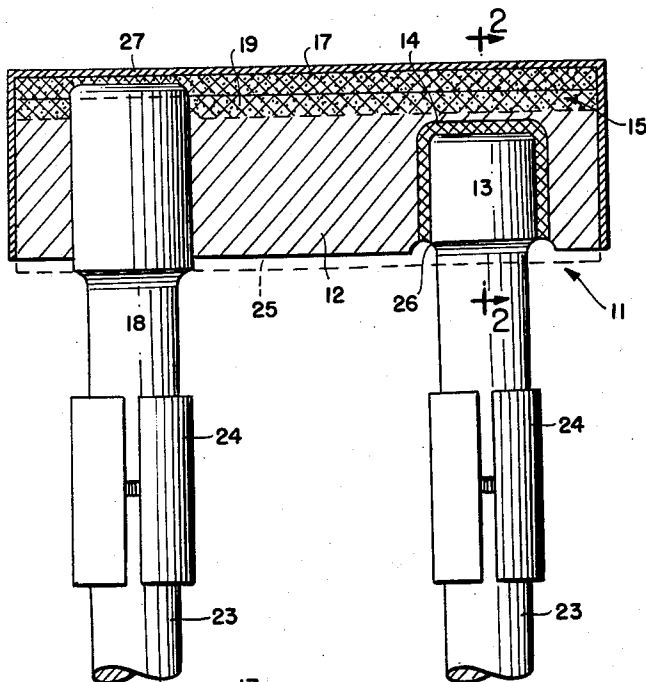


FIG. 2

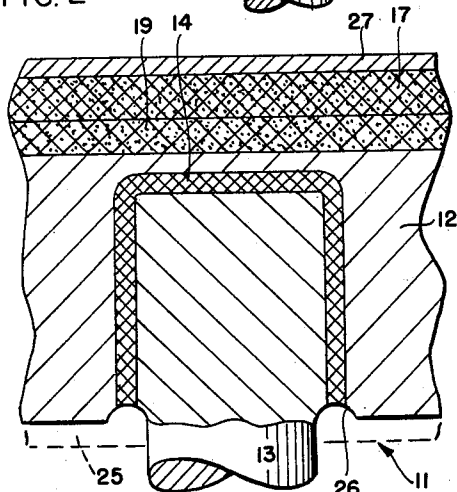


FIG. 3

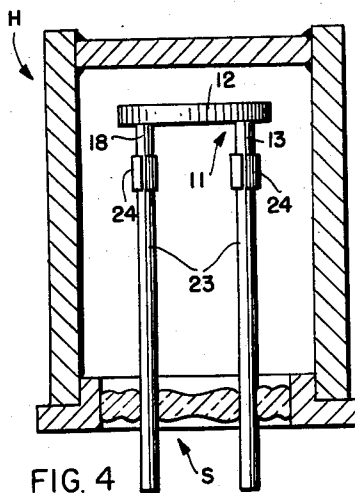
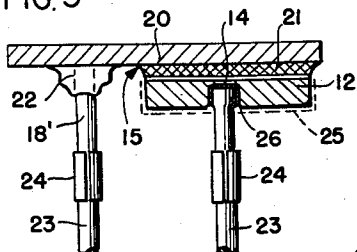


FIG. 4

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RECTIFIER AND METHOD OF MAKING SAME

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12 Claims. (Cl. 317-234)

The present invention relates, in general, to electronics, and has more particular reference to electron flow devices embodying semi-conductor material, the invention pertaining specifically to an improved electrical power rectifier comprising semi-conductor material forming a P-N junction.

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 of the material are tightly bound, and hence, unavailable for the conduction of electricity, such 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 substance to intrinsic material may be of the order of one impurity atom for each one hundred million atoms of intrinsic material. Suitable 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 negative 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

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hill, past which electrical energy may flow more easily in one direction than the other. If, for example, the 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 sides 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.

An important object of the present invention is to provide an improved rectifier of the character mentioned, the same comprising a disc or plate of semi-conductor material in which is embedded the end of a wire-like rod of selected material, in order to form a P-N junction between the material of the plate and the embedded portions of the rod; another important object being to provide for disposing the P-N junction in desired, precisely spaced relationship in the plate with respect to connection means of ohmic character through which the rectifier may be electrically connected with an electrical power source to be rectified; a further object being to provide for disposing a P-N junction in a body of semi-conducting material in precisely spaced relationship of the order of $\frac{1}{10,000}$ " with respect to means forming an ohmic contact with said body.

Another important object is to provide for the formation of an ohmic connection with the surface of a body of semi-conducting material, which consists in electroplating a film of metal, such as nickel, upon a surface of the body and then diffusing a contact promoting metal, such as gold, throughout the plated layer, to intimately connect the same in ohmic fashion with the material of the body on which applied; a further object being to diffuse such contact promoting metal in the plated layer by heating the body and layer to a temperature of the order of the melting temperature of the contact promoting metal, and then applying and embedding the end of a wire-like rod element by pressing the same into and through the material of the body and into alloy forming contact with the plated layer, whereby to diffuse the metal of said wire-like rod throughout the plated layer.

Another important object is to provide for the formation of an ohmic connection with the surface of a body of semi-conducting material which consists in electrically and mechanically securing the body upon a support plate

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of electrical conducting material having a like coefficient of thermal expansion, by means of an ohmic cement comprising low resistance metal, such as gold, adapted to wet and readily alloy with the material of the body and the support plate; a further object being to employ gold as an ohmic cement for mechanically and electrically connecting a body of semi-conducting silicon on a support plate of Kovar, or similar material.

Another important object is to provide an electrical rectifier comprising a plate or disc of silicon of selected type forming a body of semi-conducting material, and a wire-like rod of material of a different type, having an end embedded in the material of said plate, on one side thereof, to form a P-N junction between the material of the plate and the embedded end of the wire-like rod, said junction being precisely spaced a desired distance inwardly of the opposite side of the plate; a further object being to form an ohmic connection extending at the surface of said plate vertically opposite the embedded end of said wire-like, P-N junction forming rod; a further object being to employ a plate of N-type silicon in conjunction with a wire-like rod of P-type material, such as aluminum, or metal activated with an electron acceptor substance, such as boron, aluminum, indium and the like; a still further object is to employ a plate of P-type silicon in conjunction with a wire-like rod of N-type material, such as gold, activated with antimony, arsenic, phosphorus, or other electron donor substance.

Another important object is to provide an electrical rectifier comprising a plate or disc of semi-conductor material, such as appropriately doped silicon, including means forming a P-N junction therein, and means affording ohmic or low resistance connection with the body of semi-conductor material, whereby the same may be electrically inter-connected in external circuitry; a further object being to form a P-N junction for electrical rectifying purpose in a body of semi-conductor material of selected type, by embedding in said body a wire-like element of different type, and by thereafter immersing the body in acid to etch away, and hence remove the superficially exposed portions of the P-N junction at and around the wire-like rod, where the same meets the surface of the body of semi-conducting material; a further object being to coat the body of semi-conducting material with a protective layer of material, such as baked silicone lacquer, to prevent etching of the same during the junction etching process.

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 embodiment of the invention.

Referring to the drawings:

Fig. 1 is a sectional view through an electrical rectifier embodying the present invention;

Fig. 2 is an enlarged sectional view taken substantially along the line 2-2 in Fig. 1;

Fig. 3 is a sectional view illustrating a modified form of device embodying the invention; and

Fig. 4 is a sectional view through a sealed capsule or casing containing a rectifier of the sort shown in Fig. 1.

To illustrate the invention, the drawings show semi-conducting rectifier devices 11, each comprising a disc-like wafer or plate 12 of semi-conductor material of selected type, the wafer being operatively associated with a body of material 13 of unlike type, to thereby form a P-N junction 14 between the body of material 13 and the disc-like wafer 12. The wafer 12 is also operatively associated with ohmic contact means 15 forming a low resistance electrical connection with the material of the wafer in closely spaced relation with respect to the P-N junction 14.

While the present invention is not necessarily limited or restricted to any particular semi-conducting material,

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it is preferable that the disc-like wafer or plate 12 be made of silicon of desired type, the wafer preferably being of relatively thin character, having thickness of the order of, say, 5-15 mils. The wafer or plate 12 also preferably comprises N-type silicon, although plates of P-type silicon may be employed if desired in producing devices embodying the invention. Where the plate or wafer 12 comprises N-type silicon, the body 13 may comprise a wire-like rod of aluminum, having an end embedded in the wafer, the aluminum rod comprising P-type material adapted to form the P-N junction 14 between the embedded end of the rod and the surrounding N-type material of the wafer. If desired, the material of the wafer 12 may comprise P-type silicon, in which case the wire-like rod forming the body 13 may comprise N-type material, such as gold doped with an electron donor material, such as antimony, arsenic, bismuth, phosphorus and the like, in order to form a P-N junction between the embedded end of the rod and the surrounding material of the wafer.

In order to form the P-N junction 14 within the body of the wafer or plate 12, in relatively closely spaced relation with respect to and behind the front face thereof, the wafer 12 may be placed upon a heating element which may comprise a Nichrome ribbon electrically energized as a heater, at a temperature of the order of 800° C. After the wafer has been allowed to reach an equilibrium temperature, the end of the wire-like rod 13 may be applied to the back of the wafer, thereby causing the surfaces of the rod instantly to fuse and to alloy with the material of the wafer because of its high temperature. Thereafter, the rod may be pressed into the material of the wafer through a precisely determined distance measured along the rod, in order to dispose the end of the rod at a precisely selected distance inwardly of the front surface of the wafer.

As a result of softening the wafer embedded end of the wire-like rod, a sort of head, or fillet is formed thereon between which head or fillet and the surrounding material of the wafer, the P-N junction layer 14 is formed. The rod 13 thus should be applied in such fashion as to stop short of the front surface of the wafer, thereby producing a desirable, extremely thin section of semi-conducting silicon between the end of the rod 13 and the ohmic connection 15, applied at the adjacent front face of the wafer. Where the silicon section which extends between the P-N junction and the ohmic contact is extremely thin, the structure has a high rectification ratio and unusual efficiency. In order to obtain penetration of the wire-like rod 13 in the body of the wafer 12 in desired fashion, the wafer may be maintained at a temperature of the order of 800° C. during an initial period of, say, five seconds, during which the rod is applied to desired depth in the body of the wafer. Thereafter the temperature of the wafer may be reduced to a level of the order of 500° C. and held for an interval of the order of ten seconds, then reduced to a level of the order of 300° C. for an interval of the order of ten seconds, and thereafter allowed to progressively cool down to room temperature by natural radiation, such temperature programming being designed to control the alloying of the rod material with that of the wafer, at a desired rate.

As shown more particularly in Figs. 1 and 2 of the drawings, the ohmic connection 15 may comprise a layer or coating of nickel 17 which may be applied upon the front face of the wafer 12 prior to the embedding of the junction forming rod 13 therein, the layer 17 being suffused with a low resistance junction forming substance, such as gold, in order to provide substantially perfect electrical contact between the layer 17 and the surface of the wafer to which it is applied. Gold may be diffused in the layer 17 by applying the end of a wire-like rod of gold 18 through the body of the wafer 12, and into contact with the layer 17 at a point in said body and coating layer remote from the junction element 13. The rod 18

may thus be applied in and through the body of the wafer 12 contemporaneously with the application of the junction forming rod 13 therein; that is to say, after the wafer 12, containing the previously coated layer 17 thereon, shall have been heated to the required temperature, the rods 13 and 18 may be applied simultaneously to the back of the wafer and placed therein to desired depth to penetrate the rod 18 into contact with the layer 17, whereupon the gold immediately alloys with and permeates the lattice structure of the entire coated layer of nickel 17 and makes substantially perfect ohmic connection with the coated surface of the wafer 12. If desired, in order to enhance the ohmic or low resistance character of the connection between the layer 17 and the material of the wafer 12, the portions of said wafer at and inwardly of the surface thereof on which the layer 17 is applied, may be doped with a suitable activating substance to enhance the electronic characteristics of the material at the surface thereof. To this end, the wafer 12, where the same comprises N-type material, may be exposed, to phosphorus or other electron donor substance to obtain penetration of such substance throughout a surface zone 19 of the wafer, to thereby constitute the activated material of said zone as N+ type material. Of course, where the wafer 12 comprises P-type material, it may be activated with an electron acceptor substance, in order to constitute the zone 19 as P+ type material. The activation of the zone 19 should, of course, be accomplished prior to the application of the plated layer 17 and prior to the application of the rod-like members 13 and 18.

As shown more particularly in Fig. 3 of the drawings, the ohmic connection 15 may be accomplished by securing the forward face of the wafer 12 upon a mounting plate 20 of electrical conducting material having a coefficient of thermal expansion comparable with that of the material of the wafer 12. Where the wafer comprises silicon, the backing plate 20 may conveniently comprise Kovar metal formed as a plate having thickness of the order of 5-10 mils. The wafer 12 may be mechanically and electrically secured to a surface of the backing plate 20 by means of a layer of ohmic or low resistance cement 21 comprising the eutectic alloy of gold with silicon. Although the melting points of gold and silicon are respectively of the order of 1100° C. and 1400° C., the eutectic alloy has a melting temperature of less than 400° C. Accordingly, the wafer 12 and backing plate 20 may be electrically connected by means of the alloy layer 21 applied at relatively low temperature, after the application of the wire-like rod 13 in position in the wafer 12, which of course, may be treated to provide a bonding layer at and inwardly of its front face, and similar to the zone or layer 19.

The backing plate 20 may extend outwardly of an edge of the wafer 12, and may be electrically connected with a wire-like rod 18' of electrical conducting material, as by means of silver solder 22.

The rods 13 and 18 of the Fig. 1 embodiment, and the rods 13 and 18' of the embodiment illustrated in Fig. 3, may be employed to electrically connect the rectifier in external circuitry; and the rectifying device, together with the wire-like rods connected thereto, may be mounted within an enclosed housing H of any suitable or preferred character, forming an envelope carrying a pair of support stems 23 of electrical conducting material, in spaced relation within such envelope, said stems extending outwardly of the envelope through suitable seal means, and providing mechanical support for and electrical connection with the rectifier element within the housing. To this end, the stems 23 may comprise Kovar metal, having end portions extending within the housing, through glass-to-metal seals, and providing mechanical and electrical connection with the wire-like rods 13 and 18, or 18', as by means of so called staked connectors 24.

For optimum rectifying service, it is desirable that the wafer 12 and rod 13 be immersed for a short interval in an acid capable of dissolving both silicon and aluminum in an etching process, in order to remove superficial portions of the material of the rod and wafer, as at 25. Such an etching process serves to remove surface dirt, oxidation, and other roughnesses which may produce leakage paths at the surface of the wafer 12. A combination or mixture of concentrated nitric and hydrofluoric acids may be employed to dissolve the surface portions of the rectifier components, and thus expose smooth, continuous and uncontaminated body portions thereof. Where the material of the aluminum rod 13 joins with the material of the silicon wafer, the P-N junction forming alloy may be not at all uniform, but may be contaminated with oxides; possibly also with nitrides, gas bubbles, and other unwanted matter, which imperfections tend to impair the unidirectional current flow characteristics of the P-N junction. The so contaminated, superficially exposed edge portions of the P-N junction will also be removed as a result of the immersion of the wafer and rod in an etching acid of the character mentioned. Since the material of the eutectic alloy forming the P-N junction 14 is somewhat more readily soluble in the etching acid than is the material of the wafer 12 and of the rod 13, a shallow groove 26 may be formed at the superficially exposed edge of the P-N junction 14.

Acid immersion of the wafer 12, including the portions thereof containing the P-N junction, may be conveniently accomplished after the wafer and rods have been mechanically and electrically attached on the supporting stems 23. In order to protect the stems 23, as well as the stacked connectors 24, against the etching acid or fumes thereof, during the etching process, the same may be plated with a thin film of gold, which will not only resist such fumes of the etching acid as may reach said components, but will also materially assist in the formation of soldered connections between the stems 23 and the stacked connectors 24, and between the connectors and the rods 13 and 18, or 18'. In this connection, the stems 23 are preferably completely coated with gold from end to end, since the same facilitates electrical connection of the rectifier remote ends of the stems in external circuitry, such connection being relatively difficult of accomplishment with uncoated Kovar stems which oxidize readily, and hence are difficultly solderable.

The plated layer 17 in the embodiment shown in Figs. 1 and 2 may be deleteriously affected if exposed to the action of the etching acid. Accordingly, a protective coating 27, which may conveniently comprise a varnish of silicone material, may be applied in position coating the exposed surface and edges of the layer 17. If desired, the coating 27 may be extended upon such surface portions of the wafer 12 as it may be desirable to protect against the action of the etching acid. The protective coating 27 may be baked in situ in order to condition the same as a permanent acid resisting component of the rectifier. It is ordinarily unnecessary to protect the backing plate 20 of the device, as shown in Fig. 3, against the action of the etching acid, although, if desired, a protective coating, similar to the coating 27, may be applied and baked permanently in place upon surface portions of the plate 20 and bonding layer 21, in order to preserve the same against attack by the acid used in etching the exposed surface portions of the wafer 12.

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 and 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 hereby claimed at follows:

1. An electrical rectifier comprising a body of crystal-

line semi-conductor material, a wire-like rod of unlike material, having an end embedded in said body to form a P-N junction between the material of the body and of said rod, said rod having an end extending immediately behind and closely spaced with respect to a bounding surface of said body, a coating of nickel electroplated upon said bounding surface and suffused with atomic particles of gold, in order to form ohmic, or low resistance connection between the coating and the material of the body at said bounding surface.

2. An electrical rectifier comprising a body of crystalline semi-conductor material, a wire-like rod of unlike material, having an end embedded in said body to form a P-N junction between the material of the body and of said rod, said rod having an end extending immediately behind and closely spaced with respect to a bounding surface of said body, a coating of metal electroplated upon said bounding surface, and a wire-like rod of gold embedded in said body and having an end in engagement with said coating, said coating containing gold in atomic quantities derived from said rod and diffuse throughout the material thereof.

3. An electrical rectifier comprising a body of crystalline semi-conductor material, a wire-like rod of unlike material, having an end embedded in said body to form a P-N junction between the material of the body and of said rod, said rod having an end extending immediately behind and closely spaced with respect to a bounding surface of said body, a backing plate of metal having substantially the same coefficient of thermal expansion as the material of said body, a layer of ohmic cement integrating and forming a low resistance connection between said backing plate and the bounding surface of said body.

4. An electrical rectifier comprising a body of crystalline semi-conductor material, a wire-like rod of unlike material, having an end embedded in said body to form a P-N junction between the material of the body and of said rod, said rod having an end extending immediately behind and closely spaced with respect to a bounding surface of said body, a backing plate of metal having substantially the same coefficient of thermal expansion as the material of said body, a layer of ohmic cement comprising the eutectic alloy of gold and silicon, said cement being applied in position integrating and forming a low resistance connection between said backing plate and the bounding surface of said body.

5. An electrical rectifier comprising a body of crystalline semi-conductor material, a wire-like rod of unlike material, having a peripheral end area embedded within said body to form a P-N junction between the material of the body and of said rod, said rod having an end extending immediately behind and closely spaced with respect to a bounding surface of said body, said body, at and inwardly of said surface, having atomic particles of an activator substance distributed therein to form an activated zone at said bounding surface and spaced away from said P-N junction, and means forming an ohmic or low resistance connection with the material of said zone at said bounding surface.

6. An electrical rectifier comprising a body of N-type semi-conductor material, a wire-like rod of unlike material, having a peripheral end area embedded within said body to form a P-N junction between the material of the body and of said rod, said rod having an end extending immediately behind and closely spaced with respect to a bounding surface of said body, said body, at and inwardly of said surface, having atomic particles of phosphorus distributed therein to form an activated zone of N+ type material at said bounding surface end spaced away from said P-N junction, and means forming an ohmic or low resistance connection with the material of said zone at said bounding surface.

7. An electrical rectifier comprising a body of N-type semi-conductor material, a wire-like rod of unlike material, having a peripheral end area embedded within said

body to form a P-N junction between the material of the body and of said rod, said rod having an end extending immediately behind and closely spaced with respect to a bounding surface of said body, said body, at and inwardly of said surface, having atomic particles of phosphorus distributed therein to form an activated zone of N+ type material at said bounding surface and spaced away from said P-N junction, and a coating of metal upon said bounding surface, said coating containing atomic particles of low resistance contact forming metal diffused therein to provide ohmic or low resistance connection between said coating and the material of said zone at said bounding surface.

8. An electrical rectifier as set forth in claim 4, wherein the surface portions of said body or wafer of semi-conducting material, including the exposed edge portions of the P-N junction, are etched with acid to condition the same for optimum rectifying service.

9. An electrical rectifier as set forth in claim 4, including a superficial covering film of acid resistant material applied upon surface portions of the rectifier.

10. The method of making an electrical rectifier embodying a plate of crystalline semi-conductor material, which consists in first applying a metal coating upon the front surface of the plate, thereafter heating the plate to a temperature of the order of the melting temperature of its constituent material, then pressing a pair of wire-like metal rods endwise into the back of said plate, in order to embed the end of one rod to a desired depth within the body of the plate inwardly of said front surface to form a P-N junction between the embedded end of said rod and the surrounding material of said plate, while simultaneously pressing the other rod through the plate and into contact with said metal coating, to thereby diffuse atomic particles of said rod in said coating to form ohmic or low resistance connection thereof with the material of said plate.

11. An electrical rectifier comprising a body of crystalline semi-conductor material of one type of conductivity, a wire-like rod of a material of another type of conductivity, an end portion only of said rod being embedded within said body to form a P-N junction between the material of said body and of said rod, said rod having a substantially flat end portion positioned closely adjacent to and intimately associated with a surface of said body, and means forming an ohmic or low resistance connection with said body on said surface opposite said embedded end of said rod.

12. An electrical rectifier comprising a body of crystalline semi-conductor material of one type of conductivity, a wire-like rod of a material of another type of conductivity, an end portion only of said rod being embedded within said body to form a P-N junction between the material of the body and of said rod, said rod having an end portion positioned closely adjacent to and intimately associated with a surface of said body, and a metallic coating on said surface at least in the vicinity of the embedded end of said rod, said coating being suffused with a low resistance contact forming metal in order to provide an ohmic or low resistance contact with said body at said surface.

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