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B. ROSS

2,863,105

RECTIFYING DEVICE

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FIG. 1

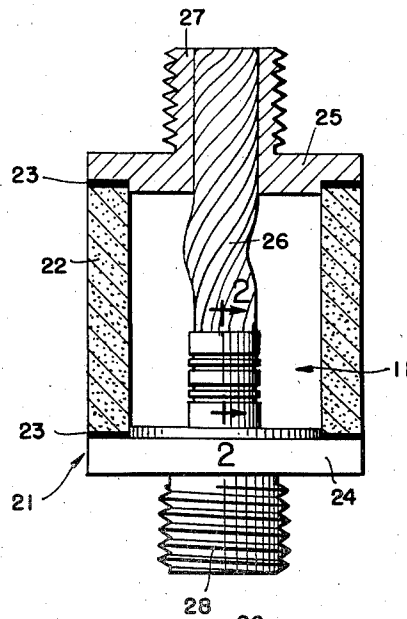


FIG. 2

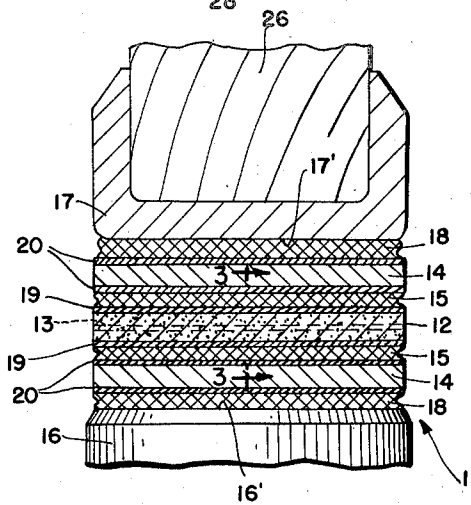
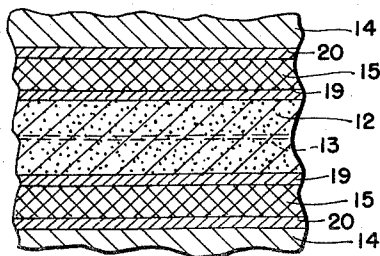


FIG. 3



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ATTORNEYS

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RECTIFYING DEVICE

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4 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

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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 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 a power rectifier comprising a body of semi-conductor material forming a P—N junction; a further object of the invention being to provide a power rectifier comprising a plate or disc of intrinsic semi-conductor material conditioned respectively as N-type and P-type material, on opposite sides of a plane extending medially of the plate between the opposite surfaces thereof; yet another object of the invention is to provide a P—N junction extending medially of the opposite faces of a disc or plate of intrinsic semi-conductor material, by dispersing atomic particles of electron donor and electron acceptor substances within the material of the plate respectively on opposite sides of a plane extending medially between the opposite faces thereof; a still further object being to expose the opposite sides of the plate respectively to electron acceptor and electron donor substances in evaporated condition, to thereby obtain penetration of said substances in the material of the plate respectively on opposite sides of a plane extending medially between the opposed faces of the plate.

Another important object of the invention is to provide a P—N junction in a disc or plate of intrinsic semi-conductor material by exposing the opposite sides of the plate successively in atmospheres respectively comprising electron acceptor and electron donor substances in vaporized condition, to first obtain penetration of atomic particles of one substance into the material of the plate to desired depth on one side thereof, and thereafter to obtain penetration of the other substance to desired depth in the material of the plate on the opposite side thereof.

Another important object of the present invention is to provide a power rectifier comprising a plate or disc of

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semi-conductor material forming a P—N junction between the opposite faces of the plate, and means for electrically connecting, in ohmic or low resistance fashion, the opposite faces of said plate in external circuitry; a further object being to assemble the rectifying plate between mounting plates of electrical conducting, preferably metallic, material having thermal expansion characteristics substantially similar to that of the constituent material of the plate forming the rectifying element; a further object being to interpose layers of relatively soft material capable of conducting heat and electricity between the mounting plates and the disc or plate forming the rectifying element; a further object being to utilize lead or tin as a relatively soft flowable material between the mounting plates and the rectifying element.

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 taken 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; and

Fig. 3 is an additionally enlarged sectional view taken substantially along the line 3—3 in Fig. 2.

To illustrate the invention, the drawings show an electrical rectifier 11 comprising a plate or disc 12 of semi-conducting material having oppositely facing boundary surfaces, the material of the plate or disc being conditioned to provide a P—N junction 13 extending in the disc along a plane disposed medially between the oppositely facing surfaces thereof, the rectifier including means for mechanically supporting the disc 12, and for electrically connecting its oppositely facing surfaces in external circuitry, said support and electrical connection forming means being adapted, also, to dissipate heat and accommodate thermal expansion of the parts, to thereby maintain adequate electrical connection with the rectifying element 12, despite any distortion of the parts that may occur due to the production of heat in the rectifying element when the device is in service.

The disc 12 forming the rectifying element may comprise a disc-like wafer of any suitable semi-conductor material, such as silicon, germanium, or other preferred intrinsic material. The disc or wafer may be treated to condition the material thereof, on opposite sides of a plane extending medially between the oppositely facing surfaces of the disc, respectively as N-type and P-type material, to thereby form the P—N junction 13 between such P-type and N-type portions of the disc. To this end, the disc may be treated to diffuse phosphorus or other electron donor material, such as antimony, arsenic, bismuth and the like, in the material of the disc on one side thereof, whereby to constitute the material of the disc on said side as N-type material. Thereafter, the disc may be treated to diffuse boron or other electron acceptor material such as thallium, gallium, indium and the like, into the material of the disc constituting the other side thereof, in order to constitute the same as P-type material. Diffusion of electron donor and acceptor materials as activating substances in the disc 12 may be accomplished by first exposing at least one side of the disc in an atmosphere of vaporized phosphorus, or other electron donor material, for the period of time required to obtain penetration of the activating substance to desired depth at and inwardly of the exposed surface of the plate. Thereafter the opposite side of the plate may be exposed in an atmosphere comprising vaporized boron, or other electron acceptor material, to obtain penetration of the activating substance to desired depth inwardly of the so exposed surface of the disc. The diffusion of activating

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substances of unlike character, that is to say, electron acceptor and electron donor materials, into the material forming the opposite sides of the disc or plate 12, will result in constituting the material on opposite sides of the plate respectively as N-type and P-type material, thus establishing the P—N junction 13 within the body of the plate 12, substantially along a plane extending medially between the oppositely facing surfaces of the plate.

In order to support the plate forming the rectifying element, and electrically connect the same in external circuitry, the present invention contemplates mounting the disc 12 between a pair of plate-like support members 14 of material such as tungsten or molybdenum having thermal expansion characteristics substantially similar to the expansion characteristics of the material of the disc 12, bonding layers 15 of relatively soft flowable material comprising a good conductor of heat and electricity being interposed between the facing surfaces of the mounting members 14 and the plate 12. The assembly comprising the plate-like elements 12, 14 and 15 secured together in stacked relation by the layers 15 of soft material may, in turn, be supported by and between a pair of abutment members 16 and 17, which may conveniently comprise copper, said abutment members providing flat, spaced apart and mutually facing surfaces 16' and 17' between which the members 12 and 14 and the layers 15 may be mechanically and electrically connected, as by means of anchoring layers 18, preferably of soft flowable material similar to the material of the layers 15, such material preferably comprising tin, lead, silver or silver solder.

The disc forming the rectifying element 12, the mounting plates 14 and the abutment members 16 and 17 may have diametrical dimensions of the order of one-eighth of an inch. The disc 12 may have thickness of the order of 5–10 mils, while the mounting plates 14 preferably are somewhat thinner than the disc 12, having thickness of the order of, say, 5 mils. The bonding layers 15 and 18 may have thickness of the order of 1–5 mils, the same being preferably somewhat thinner than the mounting plates 14. In order to form a good mechanical and electrical bond between the faces of the members 12 and 14 and the material of the layers 15 and 18, the oppositely facing surfaces of the plates 12 and 14 are preferably coated with a thin film of metal, such as nickel or silver, as by electroplating the said surfaces of the plates. In this connection, the oppositely facing surfaces of the disc 12 are preferably coated with a thin layer 19 of nickel which may be electroplated thereon to a depth of the order of 0.0005". The oppositely facing surfaces of the mounting plates 14 also may be similarly coated with thin layers 20 of silver. If desired, the surfaces 16' and 17' of the abutment members likewise may be coated with silver, so that the entire structure, including the plates 12 and 14, the abutment members 16 and 17 and the layers of soft flowable material 15 and 18, may be integrated together by heating the same sufficiently to cause the material of the layers 15 and 18 to alloy with the members 12, 14, 16 and 17 and with the coating layers 19 and 20.

In the foregoing assembly, the plate-like members 14 provide structural elements substantially matching the thermal expansion characteristics of the material of the disc 12, thereby aiding in maintaining the layers 15, of relatively soft material, in place. The plates 14 also serve to shield the disc 12 from the undesirable effects of the substantially different thermal characteristics of the cuprous material of the abutment members 16 and 17, while still providing desirable heat and electrical conducting characteristics. The layers 15 and 18 of relatively soft flowable material function, not only to transmit heat and electricity, but also serve to accommodate any thermal expansion difference that may occur between the members 12, 14, 16 and 18, as the result of heat generation during operation of the power rectifier, as such.

The rectifier assembly may be mounted within an en-

closing housing 21, which may conveniently comprise an open ended sleeve 22 of suitable insulating material. To this end, the sleeve preferably comprises a ceramic material with a coating of metal 23 applied at the opposite ends of the sleeve. One end of the sleeve may be closed by a cover plate or disc 24, which disc preferably comprises metal, such as copper, with which the metal coated end 23 may be hermetically sealed.

The plate 24 preferably carries the abutment member 16 mechanically and electrically connected therewith in position enclosed within the housing wall 22. The rectifier assembly, including the disc members 12 and 14, the abutment members 16 and 17, and the bonding layers 15 and 18, is thus mechanically secured upon the cover plate 14 and electrically connected therewith on one side of the rectifier.

The end of the sleeve 22 remote from the cover plate 24 may likewise be enclosed by means of a plate-like cover member 25, preferably formed of metal, such as copper, and hermetically sealed with the metal coated end of the sleeve, the cover 25 being electrically connected with the abutment member 17, as by means of a preferably flexible cable 26. To this end, the cover member 25 may be provided with a central, axially extending sleeve 27 which may be externally threaded to facilitate electrical connection thereof in external circuitry, said sleeve being adapted to snugly receive the end of the flexible cable 26, which may be soldered in the sleeve to assure electrical connection of the cable therewith. The abutment member 17 is preferably of cup shaped configuration forming a socket for snugly receiving the end of the cable 26 remote from the sleeve 27; and the cable may be solderingly connected with the abutment member 17 to assure a good electrical connection between the sleeve 27 and the side of the rectifier device remote from the mounting abutment 16. In order to provide for and facilitate electrical connection, in external circuitry, of the side of the rectifier which is electrically connected with the mounting abutment 16 and the plate 24 on which said abutment is connected, the plate 24 may be provided with an externally threaded, cylindrical projection 28 which, with the externally threaded sleeve 27, provides means for easily connecting the rectifier in any electrical circuit in which it is desired to use the same.

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 as follows:

1. An electrical rectifier comprising a plate-like body of semi-conductor material activated on opposite sides of a plane medially of said body respectively with atomic

particles of electron acceptor and electron donor substances, distributed throughout said body portions, whereby to provide a P—N junction along said plane and P-type and N-type complementary zones disposed upon each side of said junction, respectively, a support plate disposed in stacked relationship with respect to one of said zones of said plate-like body, and a bonding layer of relatively soft flowable material interposed between and electrically interconnecting said plate-like body and said support plate, the layer facing surfaces of said plate-like body being coated with a thin film of nickel, the layer facing surface of said support plate being coated with a thin film of silver, whereby to promote the bonding of the material of said layer with the nickel and silver coated surfaces of the plate-like body and of said support plate.

2. An electrical rectifier comprising a plate-like body of semi-conductor material activated on opposite sides of a plane medially of said body respectively with atomic particles of electron acceptor and electron donor substances distributed throughout said body portions, whereby to provide a P—N junction along said plane, a pair of support plates disposed in stacked relationship with respect to and on opposite sides of said plate-like body, a pair of abutment members respectively disposed opposite the outwardly facing surfaces of said support plates and relatively soft bonding material forming layers interposed between and electrically connecting said plate-like body with each of said support plates, and said support plates with said abutment members.

3. An electrical rectifier as set forth in claim 2, wherein the abutment members comprise copper, the plate-like body comprises silicon, the support plates comprise tungsten or molybdenum and the soft bonding material comprises silver, tin or lead, the surfaces of the plate-like body and of the support plates being electroplated respectively with nickel and silver, and the several components being alloyingly secured together.

4. An electrical rectifier as set forth in claim 2, including an enclosing housing comprising spaced end members of electrical conducting material and an electrical insulator supporting said end members in spaced relation, one of said abutment members being electrically and mechanically connected to one of said end members and the other of said abutment members being electrically connected with the other of said end members by means of a flexible conductor, and means formed on said end members for connecting the same in external circuitry.

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